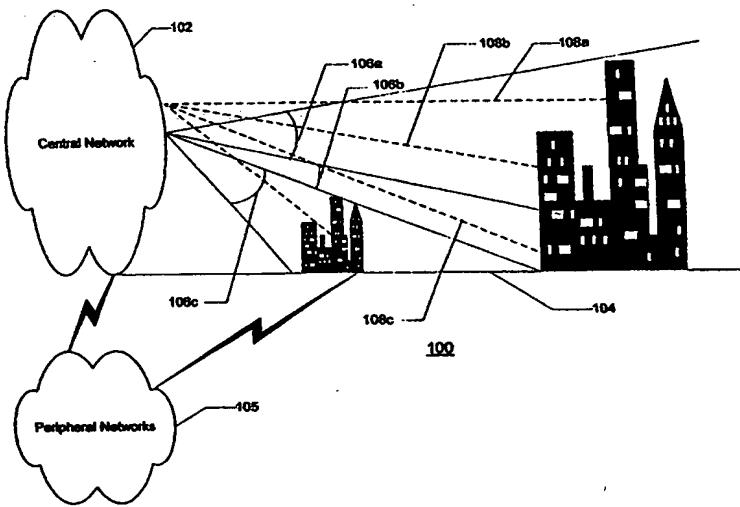




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(54) Title: OPTICAL COMMUNICATION SYSTEM THAT TRANSMITS AND RECEIVES DATA THROUGH FREE SPACE



(57) Abstract

A system and method for networked high-speed data communication through free space is described. The system includes one or more central networks, which contain one or more lasers modulated with high-speed data to illuminate with laser light areas surrounding the central network in which are located one or more user networks. The laser from the central network generates a radiation pattern that is sectored into horizontal and vertical sectors, and further divided into channels for each wavelength. Data coming from the user networks modulates a laser, which is transmitted as a collimated beam through free space back to the central network where it is received. Communication can be point-to-point, point-to-multipoint, multipoint-to-point, or multipoint-to-multipoint, and the point-to-multipoint communication can be broadcast, simulcast, or multicast.

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OPTICAL COMMUNICATION SYSTEM THAT TRANSMITS AND RECEIVES DATA THROUGH FREE SPACE

TECHNICAL FIELD

The present invention is related generally to data communication systems and, in particular, to free space optical data communication networks.

BACKGROUND OF THE INVENTION

Existing telecommunication systems may be useful for providing traditional telecommunication services, but generally are confined to relatively low-speed, low-capacity applications. For example, standard telephone lines are limited to data rates of approximately 60 kilobits per second (Kbps) per telephone line, well-known Integrated Services Digital network (ISDN) services provide data rates up to 128 Kbps, and Asymmetrical Digital Subscriber Line (ADSL) services are limited to eight megabits per second (Mbps) data rates. Similarly, conventional satellite networks can deliver data to end users at up to 15 30 Mbps per satellite, and Local Multipoint Distribution Services (LMDS) appear to have an upper limit of about four to eight gigabits per second (Gbps) per two km cell. These data rates, especially when divided between multiple users, soon prove to be insufficient for many modern applications, such as video teleconferencing and multimedia applications.

Because a typical personal computer can transmit and receive data via Ethernet at data rates in excess of 100 Mbps, individuals and businesses alike may find attractive telecommunication services that accommodate those data rates. For example, many customers may desire high-speed data communication for use with the Internet and the World Wide Web, high resolution video teleconferences, video telephony, large multi-gigabyte file transfers, etc. This means that for telecommunication service providers to thrive in today's globally competitive environment, any future telecommunication system must meet these demands without unreasonable costs.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1A is a block diagram of a communication system suitable for implementing an embodiment.

5 Figure 1B is an isometric view showing a side of the communication system of Figure 1A.

Figure 2 is a block diagram of an illustrative central network components for downlink transmission using the communication system in Figure 1B.

10 Figure 2A is a flow diagram of an illustrative central system controller transmit function.

Figure 3 is a block diagram of illustrative user network downlink reception components.

Figure 3A is a flow diagram of an illustrative user system controller transmit function.

15 Figure 3B is a flow diagram of an illustrative user system controller receive function.

Figure 4 is a block diagram of illustrative central downlink signal processor components.

20 Figure 5 is a block diagram of illustrative user downlink signal processor components.

Figure 6 is a flow diagram of an illustrative downlink data transmission and reception process.

Figure 7 is a block diagram of illustrative user network uplink transmission components.

25 Figure 8 is a block diagram of illustrative central network uplink reception components.

Figure 9 is a block diagram of illustrative user uplink signal processor components.

30 Figure 10 is a block diagram of illustrative central network uplink components.

Figure 11 is a flow diagram of an uplink data transmission and reception process.

Figure 12 illustrates a data packet suitable for use with the communication system of Figure 1A.

5 Figure 13 illustrates an illustrative transmission point with sectorization.

Figure 14 illustrates examples of various suitable radiation patterns generated by the central transmit antennas in the illustrative central network components of Figure 2.

10 Figure 15 illustrates an illustrative topography produced by the sectorization of Figure 13.

Figure 16 is a flowchart illustrating an illustrative multicast process.

Figure 17 shows an illustrative central input/output interface.

15 Figure 18 is a block diagram showing an alternative embodiment of the communication system of Figures 1A and 1B.

20 In the figures, like reference numbers refer to similar elements. In addition, the most significant digit in a reference number refers to a figure in which that element is first introduced (e.g., an element 204 is first introduced in Figure 2).

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

A communication system, and in particular, a system and method for optical communications in free space is described herein. In the following description, numerous specific details, such as specific symbols and relationships, specific methods of and structures for transmitting, receiving, and processing high speed data, etc., are set forth to provide a full understanding of embodiments of the invention. One skilled in the relevant art, however, will readily recognize that the invention can be practiced without one or more of the specific details, or with other methods and structures, etc. In other instances,

well-known structures or operations are not shown in detail to avoid obscuring the description of the embodiments.

Embodiments of the invention are directed to systems, methods, and interconnected devices for networked, high-speed, bi-directional data communication through free space having one or more centrally located transmit/receive stations which use one or more lasers modulated with encrypted, high-speed (10 Mbps-10 Gbps) data and control signals to illuminate with laser light some or all of the areas surrounding the centrally located transmit/receive stations. The illuminated areas surrounding the centrally located transmit/receive stations encompass one or more user optical receivers having light gathering and filtering elements, active tracking devices, optical detectors, and demultiplexing and decoding circuitry, which receive and select portions of the centrally located transmit/receive stations laser high-speed data stream for output to a user optical transceiver interface output, which is in turn may be connected via a high-speed networking connection to user equipment.

Data coming from user equipment on a 100 Mbps megabit Ethernet goes to the user optical transceiver interface input and modulates a laser collocated in the user optical transceiver. The user optical transceiver sends a collimated laser beam through free space back to the centrally located transmit/receive stations, where the collimated laser beam is received by light gathering and filtering elements, and active and actively tracking matrix detectors, where the data is detected and directed into data routing circuits. The data routing circuits route the data to node addresses, which can be either within one centrally located transmit/receive station area or within other centrally located transmit/receive station areas, via a high-speed free space optical backbone network-to-network links or anywhere on other networks connected to the centrally located transmit/receive stations(s) routing circuitry.

The centrally located transmit/receive stations routing circuitry also routes incoming data addressed to any or all user optical transceiver(s) by encoding that data into the high-speed data stream of the particular centrally

located transmit/receive station laser being detected by the respective user optical transceiver. The laser beams illuminate the area surrounding the centrally located transmit/receive stations in a variety of radiation patterns. The radiation patterns are sectored horizontally (or radially) and/or vertically (or by elevation).

5 The sectors may be further subdivided into several wavelength channels. The networks transmit and receive data using the channels.

Of course, those skilled in the art will appreciate that the invention is not limited to this embodiment. Instead, the invention supports a variety of embodiments, some of which are described more fully below.

10 **The Communication System**

Figure 1A is a block diagram of a communication system 100 suitable for implementing an embodiment. The communication system 100 can be thought of as a hierarchic system with a set of interconnected networks, where each network is a node in the communication system 100, and where each 15 network is interconnected. For example, the communication system 100 can include as nodes one or more central networks 102, user networks 104, and/or peripheral networks 105.

Data is exchanged among the networks. In one embodiment of the invention, data is sent from the central networks 102 to the user networks 104 20 using shaped and diverging coherent light beams (or light cones) 106, and data is sent from the user networks 104 to the central networks 102 using collimated light beams 108. Each individual network also can include a hierarchy of interrelated subsystems with lower level nodes (or network elements), which is described more fully below. Data is exchanged among the networks point-to-point, point-to-multipoint, multipoint-to-point, or multipoint-to-multipoint, and point-to-multipoint communication can be broadcast, multicast, or simulcast.

For example, during point-to-point communication, any one of the central networks 102 or their lower level nodes can transmit data from itself to any one node in the user networks 104 or the peripheral networks 105. Likewise,

any of the central networks **102** or their lower level nodes can receive data from any one of the user networks **104** or their lower level nodes, as well as from any one of the peripheral networks **105** or their lower level nodes.

During point-to-multipoint communication, any one of the central networks **102** or their lower level nodes can transmit data from itself to several user networks **104** or their lower level nodes substantially simultaneously. Any one of the central networks **102** or their lower level nodes can transmit data from itself to several peripheral networks **105** or their lower level nodes substantially simultaneously. Likewise, any of the central networks **102** or their lower level nodes can receive data from any of the user networks **104** or their lower level nodes substantially simultaneously, as well as from any of the peripheral networks **105** or their lower level nodes substantially simultaneously.

The hierarchy of the communication system **100** can feature networks interconnected with each other, as Figure 1A illustrates. The embodiment does not require that the peripheral networks **105** and the user networks **104** be interconnected, or that the central networks **102** be connected to both the peripheral networks **105** and the user networks **104**. Moreover, the central networks **102** may be interconnected to each other such that data is transmitted among the individual central networks **102** without passing through a peripheral network **105** or a user network **104**. This particular embodiment reduces the costs of operation, for example, by allowing central networks to carry their own backbone traffic, unlike other wireless networks that dedicate all of their bandwidth to the user networks.

In one embodiment of the invention, a user network **104** is operated by a user that subscribes with the peripheral networks **105** and/or the central networks **102** to send and receive data in a client-server environment. The users may be located at a manufacturing facility, a multinational corporation, a financial institution, or a university, for example, with buildings that house the network components. In that instance, the central networks **102**, the user networks **104**, and the peripheral networks **105** connect "client" systems with

“server” systems so that the server systems may perform a computation, retrieve a file, or search a database for a particular entry in response to a request by the client system. A particular type of client-server environment is not essential to the embodiment. It will be apparent to those skilled in the art that the 5 embodiments may be implemented in other client-server environments, such as airline flight reservations systems, mail-order facilities, etc.

The peripheral networks **105** can be any interconnected network operated by a common carrier, including a Public Switched Telephone Network (PSTN), a Local Exchange Carrier (LEC) network providing local 10 telecommunication services, an Interexchange Carrier (IXC) providing long distance telecommunication services, a satellite network, a value added network (e.g., providing dial-up stock market quoting services, electronic mail services, etc.). Alternatively, the peripheral networks **105** can be a collection of networks functioning as a virtual network, including the Internet, the World Wide Web, 15 etc. The peripheral networks **105** also can include data communication networks such as Local Area Networks (LANs), Metropolitan Area Networks (MANs), or Wide Area Networks (WANs). Of course, those skilled in the art will appreciate that a particular type of peripheral network **105** is not required by the embodiment. Instead, any type of peripheral network **105** may be used.

20 In one embodiment, the central networks **102**, the user networks **104**, and the peripheral networks **105** utilize Synchronous Optical Network (SONET) technology, which is an optical interface standard that allows internetworking of transmission products from multiple vendors. That is, when the communication system **100** implements SONET technology, interconnection 25 of the networks enables worldwide data communication. Moreover, when the communication system **100** implements SONET technology, a new digital hierarchy ideally suited to handling fiber-based signals and at the same time allowing easy extraction of lower rate signals is accomplished. These include unified operations and maintenance and the flexibility to allow for future service 30 offerings.

In an alternative embodiment, the central networks 102, the user networks 104, and the peripheral networks 105 utilize Gigabit Ethernet technology, which is an optical interface standard that allows internetworking of transmission products from multiple vendors. That is, when the communication system 100 implements Gigabit Ethernet technology, interconnection of the networks enables worldwide data communication, especially real-time voice and video and high-end server support. Moreover, when the communication system 100 implements Gigabit Ethernet technology, a new digital hierarchy ideally suited to handling fiber-based signals and at the same time allowing easy extraction of lower rate signals is accomplished. These include unified operations and maintenance and the flexibility to allow for future service offerings.

Figure 1B is an isometric view showing a side of the communication system 100, where data is exchanged between the central networks 102 and the user networks 104 in free space using the light cones 106a-c and the collimated light beams 108a-c. In one embodiment, the light cones 106a-c are shaped and diverging coherent light beams, such as light amplification of stimulated emission of radiation, or "laser" beams. Laser beams are directional, and can operate in a range of wavelengths in the "light" region of the electromagnetic spectrum, including visible light, near-infrared light, and infrared light. When the light cones 106a-c are laser beams, the light cones 106a-c accommodate high bit rate, high power, high coupling efficiency, direct high frequency modulation, and long haul operations. In one embodiment, the light cones 106a-c are eye-safe, class one laser beams, in accordance with American National Standards Institute (ANSI) standards. In alternative embodiments, the light cones 106a-c operate in accordance with other ANSI standards.

The use of particular wavelengths of laser light provides high bandwidth with very little attenuation (or power loss) in the atmosphere. Moreover, using laser light allows interconnection with SONET architectures

operating at high speeds between central networks 102 typical of off-the-shelf data transmission equipment currently available. Moreover, in this embodiment, using the SONET protocol allows arbitrary bandwidth allocation in the well-known portions of T-1 capacity. That is, when the communication system 100 5 uses the laser lights with SONET, it can accommodate a digital transmission link with the capacity of 1.544 Mbps to many different users across remote distances.

One embodiment of the communication system 100 uses an infrared laser with a wavelength of approximately 1550nm. Of course, those skilled in the art will appreciate that a particular wavelength in the light region of 10 the electromagnetic spectrum is not required by the embodiment. Instead, any wavelength in the light region may be used.

The light cones 106a-c and the collimated light beams 108a-c can be generated using any well-known holographic optical elements that shape, filter, and diverge or collimate the light appropriately. For example, beam 15 shaping can be accomplished using diffraction gratings, lenses, holographic optical elements, or other standard beam-shaping optic. Wavelength filtering, used in various channelization schemes, can also be achieved using a variety of standard optical components such as interference filters, diffraction gratings, or prisms.

As is described more fully below, the light cones 106a-c bit rate in 20 one embodiment may be between 10 Mbps and 10 Gbps, inclusive. Of course, those skilled in the relevant art will appreciate that a particular data rate is not required for the embodiment. That is, the embodiments of the invention support any number of data rates.

As is the case with the light cones 106a-c, the collimated light 25 beams 108a-c also can be laser beams or any light beam at a wavelength in the "light" region of the electromagnetic spectrum, including visible light, near-infrared light, and infrared light. Collimating can be accomplished in a well-known manner, such as by using a diffraction gratings, lenses, or other standard 30 beam-shaping optics.

Of course, those skilled in the art will appreciate that, while much of the communications within the communication system 100 involves the wireless exchange of extremely high-speed, broadcast, digital data, the communication network 100 also supports conventional methods of data communication, such as telephone lines. For example, a central network 102 can transmit Internet video data at an extremely high speed to a user network 104 using a light cone 106a, with the return communication from the user network 104 to the central network 102 being via a standard telephone line. This may be the case when the Internet data is graphics and text, and the user data is credit card information, for example. This also may be the case when the Internet data is graphics and text, and the user data is user authorization information, for example.

Moreover, those skilled in the art will appreciate that, while the communication system 100 can involve the wireless exchange of extremely high-speed, broadcast, digital data, the communication system 100 can use other data rates. That is, the communication system 100 can communicate at data rates commensurate with the type service being provided, the quality of service requested, type of information transmitted and/or received, etc.

Downlink Transmission and Reception Structure

Figure 2 is a block diagram of illustrative central network 102 downlink transmission components. In this embodiment, the peripheral networks 105 send data for transmission to the user networks 104 via a central router/switcher 204, a central downlink signal processor 206, and a central transmit antenna 208. A central system controller 210 controls the operation of the central router/switcher 204 and the central downlink signal processor 206. Generally, data travels along the thick interconnection lines, while other commands, control signals, etc., travel along the thin interconnection lines. Data and other commands, control signals, etc., may also travel on thin and thick interconnection lines, respectively.

For purposes of explanation, only one central network **102** is described with respect to certain aspects of the embodiment of Figure 2. It is to be understood that the embodiment contemplates one or more central networks **102**.

5 The central router/switcher **204** connects the central network **102** to the peripheral networks **105** and to the user networks **104**, enabling data to be exchanged between them. The central router/switcher **204** can interconnect network interface controllers (NICs), disk controllers, graphic display adapters, etc., to the central network **102**. For example, the central router/switcher **204**
10 supports NICs implemented in a G-NIC Network Interface Card available from Packet Engines of Spokane, Washington, adapted from 830nm to 1550nm.

Other illustrative central router/switcher **204** implementations include well-known 10/100 Mbps Ethernet NICs with 64-bit Peripheral Component Interconnect (PCI) buses, which support either Windows NT™ or
15 the Digital UNIX® operating system. When the peripheral network **105** is the Internet, the central router/switcher **204** can support Internet points of presence (POPs).

The central router/switcher **204** in one embodiment is a fiber optic backbone that interconnects lower level network elements in the peripheral networks **105** or the central networks **102**. In that embodiment, and where the communication system **100** is a packet-switched network, the central router/switcher **204** is the main path for data packets. Packet-switched networks are described more fully below.

The central router/switcher **204** also interconnects the components that transmit the light cones **106** and receive the collimated light beams **108**. The central router/switcher **204** manages the routing of data through the communication system **100**. For example the central router/switcher **204** divides the central network **102** into logical software-oriented sub-networks, enabling data traffic to be more efficiently routed. The central router/switcher **204** also
30 performs load balancing, partitioning, and statistical analysis on data traffic. The

central router/switcher 204 also determines routing priorities, and performs troubleshooting tasks. The central router/switcher 204 also selects the paths that data from the light beam 108 or data to the light cone 106 will take in the communication system 100. The central router/switcher 204 may dynamically 5 route data based on the quality of service required or the amount of data traffic in the central network 102.

In one embodiment, the central router/switcher 204 implements a link state routing algorithm that calculates routes based on the number of routers, transmission speed, delays, and route costs. This embodiment can be 10 implemented using an "open shortest path first" (OSPF) protocol running on a PowerRail 5200 Gigabit Ethernet routing switch available from Packet Engines. The central router/switcher 204 also includes several queues that hold data waiting to be routed.

The central downlink signal processor 206 receives the data to be 15 sent to the user networks 104 from the central router/switcher 204 and encodes, modulates, encrypts, buffers, and amplifies the data to produce a carrier whose frequency is in the visible or near-infrared region of the electromagnetic spectrum. A carrier with such a high frequency is sometimes referred to herein as an "optical signal," an "optical carrier," a "carrier," a "carrier signal," a 20 "lightwave signal," a "light cone," or a "light beam."

The central downlink signal processor 206 also shapes the carrier signal for transmission by the central transmit antenna 208. The structure and operation of the central downlink signal processor 206 is described in greater detail below with reference to Figure 4, including queuing of data waiting to be 25 processed.

The central transmit antenna 208 transmits the carrier into free space. For purposes of explanation, only one central transmit antenna 208 is described with respect to the illustrated embodiment of the invention. It is to be understood that the embodiment can contemplate one or more central transmit

antennas per local central network and one or more central networks per geographic location.

According to an embodiment, the central transmit antenna 208 transmits the carrier into free space using geometric optics, such as refractive, 5 reflective, diffractive, or holographic optics. Imaging geometric optics (IGOs) have the capability of making an image of an object. The image may either be a “real image” or a “virtual image.” A real image is one that is cast on a screen, for example. A virtual image is viewed through an eyepiece.

To accomplish this task, an IGO has two properties: (1) Parallel 10 light rays passing through the optics are focused to a single point (the “focus”); and (2) Light rays incident from different angles are focused to different foci, all of which lie in a plane (the “focal plane”). A telescope, camera lens, shade projector, magnifying lenses, and contact lenses are examples of imaging geometric optics.

15 Non-imaging geometric optics (NGOs) do not satisfy at least one of the criterion necessary for an IGO. If one tries to observe an image created by NGOs, the image will either be “fuzzy” or nonexistent. Examples of NGOs are the Fresnel lenses used in front of motor vehicle headlights or the rippled “privacy” glass used in certain windows where privacy is required.

20 A diffraction grating is an example of an NGO suitable for implementing one embodiment of the invention. Of course, any diffraction grating suitable for focusing the desired wavelength that can focus the light cone 106 into a small enough spot could be used. In this embodiment, a diameter for the light cone 106 is 60 microns. Those skilled in the art will appreciate that the 25 particular diameter is dependent upon the desired data rate.

Although IGOs are adequate, they are expensive and the embodiment does not require all of their capabilities. Thus, one embodiment uses NGOs to maximize the utility of the system while minimizing the cost of the transmit and receive optics. A suitable non-imaging geometric optic operating in 30 the 1550nm range is available from Richardson Labs in Meridian, Idaho.

The central system controller 210 controls the operation of the central router/switcher 204, and the central downlink signal processor 206. The central system controller 210 can be implemented in hardware, software, or a combination of both hardware and software. In aspects that are implemented 5 using software, the software may be stored on a computer program product (such as an optical disk, a magnetic disk, a floppy disk, etc.) or a program storage device (such as an optical disk drive, a magnetic disk drive, a floppy disk drive, etc.). The central system controller 210 may also be custom software running on a composite of computers (or processors).

10 Figure 2A illustrates a flow diagram of a central system controller 210 transmit function 200 suitable for implementing the custom software running on a composite of computers. Operation of the transmit function 200 begins with step 211, where control immediately passes to step 212. In step 212, the transmit function 200 determines which of its data queues advances next to send data to 15 the central downlink signal processor 206. In step 214, the transmit function 200 synchronizes encoding and multiplexing schemes. In an embodiment, a user system controller 310 (see, e.g., Figure 3) synchronizes encoding and multiplexing schemes with the user networks 104. That is, the central system controller 210 performs handshaking with the user networks 104 to initiate a data 20 transfer.

In step 216, the transmit function 200 determines the particular encoding required. Typically, the user networks 104 control the encryption scheme, while the central networks 102 control the multiplexing and encoding schemes. Thus, in an embodiment, the central controller 210 determines the 25 particular encoding required.

In step 218, the transmit function 200 decides when a data packet is to be transmitted. In an embodiment, the central system controller 310 makes this decision. Operation of the transmit function 200 is complete following step 218, as indicated by step 220.

The output of the central networks 102 on the downlink are the light cones 106, which are transmitted into free space and received by the user networks 104. That is, each of the central networks 102 transmits data modulated on a shaped and diverging coherent or other light beam through free space.

Figure 3 is a block diagram of illustrative user network 104 downlink reception components. A user antenna 302 receives data transmitted from the central network 102, processes it using a user downlink signal processor 304, and sends the data to user equipment and devices 308, the user system controller 310, and/or any of the peripheral networks 105. For purposes of explanation, only one user network 104 may be described with respect to certain aspects of the embodiment shown in Figure 3. It is to be understood that embodiments of the invention contemplate one or more user networks 104.

As mentioned above, the user antenna 302 receives the light cones 106 from free space. The user antenna 302 receives the light cones 106 using an optical receiving antenna, which, in one embodiment, uses holographic optical elements. One embodiment uses well-known telescopes to receive the light cones 106. For example, the user antenna 302 can be a reflective telescope with a modified eyepiece to further confine the spot size of the received light. The user antenna 302 outputs the received light cones 106 to the user downlink signal processor 304.

The user downlink signal processor 304 receives the light cone 106 and decodes, demodulates, decrypts, and buffers it to separate the data from the carrier. The structure and operation of the user downlink signal processor 304 is described in greater detail below with reference to Figure 5.

The user input/output interface 306 interconnects the user equipment 308, the user system controller 310, and the peripheral networks 105. Recall that in one embodiment, the user network 104 is operated by a user that subscribes to send and receive data in a client-server environment, such that the central networks 102, the user networks 104, and the peripheral networks 105

connect "client" systems with "server" systems. The user input/output interface **306** interconnects the client systems with the server systems using appropriate signaling and protocols. In one aspect, the user input/output interface **306** supports well-known full-duplex operation and flow control common to client-server environments. In another aspect, the user input/output interface **306** supports Signaling Network Management Protocol (SNMP), which is a well-known method by which network management applications query a management agent using a supported Management Information Base (MIB). This embodiment manages virtually any network type, to include Non-Transmission Control Protocol (non-TCP) devices, such as IEEE 802.1 Ethernet bridges.

The user input/output interface **306** supports bidirectional encryption, with the ability to change keys as needed. The user input/output interface **306** also implements "challenge" and "reply" authentication when setting the keys. In this embodiment, the user input/output interface **306** has a unique serial number, even though it does not have a unique network address, which serial number can be used for encryption and other security features. The firmware on the subscriber input/output interface **306** also is protected from hacking.

The user equipment and devices **308** can be any of a variety of well-known equipment, such as gateways, local area networks, bridges, etc. The user equipment and devices **308** also can be any of a number of well-known user devices, such as printers, hard drives, graphical display adapters, televisions (TVs), TV set top boxes, telecommunication equipment, video conferencing equipment, and audio/visual equipment, such as home theater electronics, etc.

The user system controller **310** operation and structure are similar to the operation and structure of the central system controller **210**, in that the user system controller **310** controls the operation of the user downlink signal processor **304** and the user input/output interface **306**. The user system controller **310** likewise can be implemented in hardware, software, or a combination of both hardware and software. In embodiments that are implemented using software,

the software may be stored on a computer program product (such as an optical disk, a magnetic disk, a floppy disk, etc.) or a program storage device (such as an optical disk drive, a magnetic disk drive, a floppy disk drive, etc.).

5 The user system controller 310 may also be custom software running on a composite of computers (or processors). In one embodiment, the user system controller 310 is implemented in a token ring time-division multiplex (TDM) system.

10 Figure 3A illustrates a flow diagram of a data transmit routine 300 suitable for use with the user system controller 310 in this embodiment. The transmit routine 300 begins with step 311, where control immediately passes to step 312 wherein the transmit routine 300 determines the type, amount, and rate of data to be transmitted.

15 In step 314, the transmit routine 300 communicates the information gathered in step 312 to the central system controller 210. In step 316, the transmit routine 300 transmits data during the life of the token. In step 317, the transmit routine 300 determines if no more data exist, and in step 318 returns a token to the central system controller 210. If in step 318, no more data returns a token to the central system controller 210, the transmit routine 300 returns to step 312.

20 In step 320, if there is more data, the transmit routine 300 waits for the next token from the central system controller 210, and then the transmit routine 300 returns to step 312.

Figure 3B is a receive routine 350 that the user system controller 310 implements in the token ring TDM system embodiment. For example, in step 352, the receive routine 350 receives a data packet and demodulates it. In step 354, the receive routine 350 examines the data packet header, and determines if the data packet address matches a user system address.

30 In step 356, the receive routine 350 determines whether the address of the data packet matches the user's system address. If the address is a match, then control of the receive routine 350 passes to step 358, wherein the receive

routine 350 decrypts the data packet. In step 360, the receive routine 350 sends the data packet to the user's sub-network.

If, on the other hand, in step 356 it is determined that the data packet address does not match a user system address, operation of the receive 5 routine 350 passes to step 362, wherein the receive routine 350 dumps the data packet.

Figure 4 is a block diagram of illustrative central downlink signal processor 206 components. The illustrative central downlink signal processor 206 includes encoders 402, modulators 404, multiplexers 406, and power 10 amplifiers 408 that convert data into a carrier, and amplify the carrier for transmission in free space to the user networks 104.

The encoders 402 convert data into a representation of the data according to a set of rules or conventions specifying the way in which the signals representing the data can be formed, transmitted, received, and processed. In one 15 aspect, the encoders 402 encodes data and control signals into a high-speed data stream. Illustrative encoders 402 are implemented in a Media Access Controller (MAC) chip on Packet Engines' G-NIC. Of course, the encoders 402 can be implemented in any Ethernet card, switch, or repeater with the same encoding capabilities.

20 The modulators 404 modulate the light cone 106 according to the data to be transmitted on that light cone 106. There are several types of well-known modulation schemes used for communications (e.g., frequency modulation, phase modulation, phase-shift keying modulation, quadrature amplitude modulation, etc.), any of which are suitable for implementing 25 communication in the communication system 100. In one embodiment, the modulators 404 are implemented in well-known Ethernet Peripheral Component Interface (PCI) cards whose input and output are via optical fiber. In this embodiment, the modulators 404 use a well-known on-off keying (OOK) amplitude modulation scheme. The OOK amplitude modulation scheme is the 30 lowest cost modulation scheme currently available. Of course, the modulators

404 can be implemented in any Ethernet card, switch, or repeater with the same modulating capabilities. An embodiment uses the serializing/deserializing chip on Packet Engines' G-NIC to implement the modulation task, as well as to drive the laser.

5 The multiplexers **406** in one aspect are wavelength division multiplexers (WDMs) that establish optical channels by combining the wavelengths (or colors) into the light cone **106**. That is, the multiplexers **406** mix several channels at different wavelengths and output the wavelengths on the same light beam. In this aspect, the multiplexers **406** can be well-known passive
10 combiners or selective combiners. In another aspect, the multiplexers **406** are optical time division multiplexers (OTDM), or high density wavelength division multiplexers (HDWDM). Alternatively, multiplexers **406** can be implemented using coherent multi-channel heterodyne or homodyne detection techniques. In fact, any type of optical combiner that can perform the function of combining the
15 channels, such as fused filter couplers or Soliton multiplexers, also can be used to implement the multiplexers **406**. Of course, the invention is not limited by the particular type of multiplexing. For example, the channels can be combined into the light cone **106** using frequency, polarization, spatial position, polarity, space, algebraic transform methods, etc. An embodiment of the multiplexers **406** uses a
20 dense wavelength division multiplexer (DWDM) to select channels at International Telecommunications Union (ITU) standards for the 1530nm-1560nm range (approximately 0.8nm separation between channels).

25 The power amplifiers **408** may receive and amplify one or more wavelengths that will be present in the light cone **106**. The power amplifiers **408** tolerate optical signals of many formats (or modulation schemes, such as polarity shift keying or amplitude shift keying) or bit rate (up to many Gbps), *e.g.*, the power amplifiers **408** are transparent. In one embodiment of the invention, one geographic locality contains three central network stations. The signals from each of these central network stations are divided into 36 sectors. Each sector is
30 capable of carrying up to eight channels at 100 Mbps to 10 Gbps each, with an

overall local geographic capacity of up to 8.650 terabits per second (Tbps) (e.g., 3 stations x 36 sectors x 8 channels x 10 Gbps.) In an embodiment, the power amplifiers are erbium doped fiber optic amplifiers (EDFA), that amplify one or more wavelengths simultaneously, available from JDS Fitel Corporation in 5 Nepean, Ontario, Canada.

Figure 5 is a block diagram of illustrative user downlink signal processor 304 components. The embodiment user downlink signal processor 304 includes light cone detectors 502, user demodulators 504, user demultiplexers 506, and user decoders 508, which detect and separate data from the carrier in the 10 light cone 106 after it is received from free space by the user antenna 302.

The light cone detectors 502 detect and focus the light cone 106 onto a photodetector (not shown). The light cone detectors 502 may include a concentrator (not shown) which concentrates the light cone 106 and focuses it without loss. After detecting and focusing, the data on the light cone 106 is 15 amplified with a preamplifier (not shown), converted to serial form with a serializer (not shown), and protocol converted using a protocol converter (not shown). The preamplifier, serializer, and protocol converter are available in a G-NIC network interface card manufactured by Packet Engines, as described above with reference to the modulators 404. In this embodiment, the protocol 20 converter can either convert the modulation of the light cone 106 to a Gigabit Ethernet format or reduce it down to a 100 Mbit format. The detectors also include well-known pattern masks, such as diffraction gratings. The light cone detectors 502 output the light cone 106 to the user demodulators 504. Illustrative light cone detectors 502 are implemented in PIN diode in an off-the-shelf 25 1550nm transceiver unit manufactured by MRV Communications located at 20415 Nordhoff Street, Chatsworth, California 91311.

The user demodulators 504 demodulate the carrier using well-known demodulation techniques compatible with the modulation schemes used by the modulators 404. For example, in one embodiment, the user demodulators 30 504 are implemented in the Ethernet PCI cards.

The user demultiplexers **506** separate the wavelengths back into frequency-separated independent optical channels using techniques compatible with the multiplexers **406**. The demultiplexers **506** can be well-known passive splitters or selective splitters.

5 The user decoders **508** convert data from the representation of the data established by the encoders **402**. For example, the user decoders **508** decodes data and control signals from a high-speed data stream. An embodiment is implemented in a MAC chip on Packet Engines' G-NIC. Of course, the user decoders **508** can be implemented in any Ethernet card, switch, or repeater with
10 the same encoding capabilities. The user decoders **508** output decoded data to the user input/output interface **306**, which then makes the data available to the peripheral networks **105**.

15 Any or all of the components in the embodiments in Figures 2 and 4 or Figures 3 and 5 can be implemented on a single card, respectively. In one embodiment of the invention, the components in Figures 2 and 4 are implemented in a single card from Packet Engines. Similarly, the components in Figures 3 and 5 are implemented in a single card from Packet Engines. Of course, those skilled in the relevant art will appreciate that a particular physical location for the components in Figures 2 and 4 or Figures 3 and 5, respectively, is
20 not essential to practice the embodiment.

Downlink Transmission and Reception Operation

Figure 6 is a flow diagram of a downlink data transmission and reception process **600** performed by the central network **102** downlink transmission components, the user network **104** downlink reception components, and the peripheral networks **105**. The process **600** starts at step **602**, where control immediately passes to step **604**. In step **604**, the central router/switcher **204** receives data from the peripheral networks **105** designated for recipients in the user networks **104** or other central networks **102**.

In step 606, the central router/switcher 204 routes the data to the central downlink signal processor 206, where in step 608, the data is processed for transmission using the encoders 402, modulators 404, multiplexers 406, and power amplifiers 408. Following encoding, modulation, multiplexing, and 5 amplifying, in step 610, the central transmit antenna 208 transmits the data into free space on the light cone 106.

In step 612, the user antenna 302 receives the light cone 106. The user downlink signal processor 304 processes the light cone 106 to remove the data from the carrier, and to separate out one or more of the channels. In step 10 614, the user input/output interface 306 sends that data to the peripheral networks 105, as indicated by step 616 and/or to the user equipment and devices 308, indicated by step 618, as appropriate. Following steps 616 and 618, operation of the process 600 is complete, as indicated by step 620.

Uplink Transmission and Reception Structure

15 Figure 7 is a block diagram of illustrative user network 104 uplink transmission components. The peripheral network 105 sends data for transmission to the central networks 102 via the user input/output interface 306 and/or the user equipment and devices 308 and sends it to a user uplink signal processor 702. The user uplink signal processor 702 outputs the data to the user 20 antenna 302 for transmission into free space on the collimated light beam 108, which is received by the central networks 102. The user uplink signal processor 702 is described more fully below with reference to Figure 9.

Figure 8 is a block diagram of illustrative central networks 102 uplink reception components. A central receive antenna 802 receives data 25 transmitted from the user networks 104, processes the data using a central uplink signal processor 804, and routes the data to the peripheral networks 105 via the central router/switcher 204. The central system controller 210 controls the operation of the central router/switcher 204 and the central uplink signal

processor **804**. The central uplink signal processor **804** is described more fully below with reference to Figure 10.

Figure 9 is a block diagram of illustrative user uplink signal processor **702** components. The illustrative user uplink signal processor **702** includes user multiplexers **902**, user modulators **904**, and user optical transmitters **906**. The multiplexers **902** operate similarly to the multiplexers **406** in the central downlink signal processor **206**, in that the multiplexers **902** can combine channels using WDM, OTDM, HDWDM, coherent multi-channel heterodyne or homodyne detection techniques, fused filter couplers, or Soliton multiplexers, for example.

The user modulators **904** operate similarly to the modulators **404** of the central downlink signal processor **206**. For example, the user modulators **904** can implement several types of well-known modulation schemes used for communications. In one aspect of the invention, the user modulators **904** are implemented in well-known Ethernet PCI cards whose input and output are via optical fiber. The user optical transmitters **906** perform well-known optical signal processing on the data prior to output to the user antenna **302**. An illustrative optical transmitter **906** includes a laser, an amplifier, and a telescope. This embodiment uses a telescope manufactured by Meade in Irvine, California, whose eyepiece has been adapted to allow a fiber optic element to be inserted into the eyepiece (so that the laser light can be sent into the telescope, and thus, transmitted into free space).

The output of the user optical transmitters **906** is sent to the user antenna **302**, which transmits the multiplexed and modulated data as the collimated light beam **108** to the central networks **102**. The central networks **102** receive the collimated light beam **108**, process it using the central uplink signal processor **804**, and send the data to any of the peripheral networks **105**.

Figure 10 is a block diagram of illustrative central network **102** uplink components. As Figure 10 shows, the central receive antenna **802** receives the collimated light beams **108** from free space. The central receive

antenna 802 receives the collimated light beams 108 using an optical receiving antenna, which, in one embodiment of the invention, uses holographic optical elements.

The central uplink signal processor 804 includes collimated beam detectors 1002, central demodulators 1004, and central demultiplexers 1006. The collimated beam detectors 1002 detect and focus the collimated light beam 108 and provide spatial offsets to spatially separate and separately detect each collimated light beam 108 whether on identical or differing wavelengths. The collimated beam detectors 1002 can be similar to a two-dimensional array of photodetectors, each receiving a collimated light beam 108 from a different user network 104 or a lower level node. The collimated beam detectors 1002 output signals corresponding to the different collimated light beams 108. The central receive antenna 802 outputs the signals corresponding to the different received collimated light beams 108 to the central demodulators 1004. In one embodiment, the collimated beam detectors 1002 focus the collimated light beam 108 onto a 1500nm detector that detects data at rates in excess of 10 Mbps. Such detector is available from MRV Communications.

The central demodulators 1004 demodulate the carrier using well-known demodulation techniques compatible with the modulation schemes used by the user modulators 904. For example, in one embodiment, the user demodulators 1004 are implemented in well-known Ethernet PCI cards.

The central demultiplexers 1006 further separate the wavelengths back into spatially independent optical channels using techniques compatible with the user multiplexers 902. As such, the central demultiplexers 1006 can be well-known passive splitters or selective splitters. The central demultiplexers 1006 output data to the central router/switcher 204, which then makes the data available to the peripheral networks 105.

Uplink Transmission and Reception Operation

Figure 11 is a flow diagram of an uplink data transmission reception process 1100 performed by the central network 102 uplink transmission components, the user network 104 uplink reception components, and the 5 peripheral networks 105. The process 1100 starts at step 1102, where control immediately passes to step 1104. In step 1104, the user input/output interface 306 receives data from the peripheral networks 105 and routes the data to the user uplink signal processor 702.

10 In step 1106, the user uplink signal processor 702 processes the data for transmission using the user multiplexers 902, user modulators 904, and user optical transmitters 906. In step 1108, the user antenna 302 transmits the data into free space on the collimated light beam 108 into free space. In step 1110, the central receive antenna 802 receives the collimated light beam 108 from free space.

15 In step 1112, the central uplink signal processor 804 invokes steps 352 through 358 of the user system controller 310 receive function 350 (see, e.g., Figure 3B) and processes the collimated light beam 108 to remove the data from the carrier, and to separate out one or more of the channels.

20 In step 1114, the central router/switcher 204 sends that data to the peripheral networks 105, as indicated by step 1114 and/or to other central networks 102, indicated by step 1116, as appropriate. Following steps 1114 and 1116, operation of the process 1100 is complete, as indicated by step 1118.

25 It is noted that it can be less expensive to transmit from the user networks 104 to the central network 102 using the collimated light beam 108 as opposed to a shaped and diverging light cone 106, as is transmitted from the central network 102 to the user networks 104. For example, the collimated light beams 108 require less power. Moreover, transmitting using the collimated light beams 108 ensures that there is little interference between bidirectional light transmissions between the central networks 102 and the user networks 104.

Recall that the communication system 100 (see, e.g., Figure 1) also supports conventional methods of data communication. Accordingly, the communication network 100 can communicate at data rates commensurate with the medium of communication. For example, the communication system 100 can 5 transmit into free space at one data rate and receive via telephone lines at a different (e.g., lower) data rate.

Data Packet Structure

As described above, the communication system 100 uses packet-switching technology, in which data is divided into individual data packets before 10 transmission and routed through different network elements and may therefore arrive at different times or out of sequence. If received out of sequence, the individual data packets are reassembled at the intended destination.

Figure 12 illustrates a data packet 1200 suitable for use with the communication system 100. The data packet 1200 includes a payload 1202, 15 which typically is the data content. For example, the data content can be stock quotes, video/audio for a teleconference, etc. Those skilled in the art will appreciate that the particular payload may vary according to the application and may include information needed to facilitate reassembly of the data packets into the original data sequence.

20 The data packet 1200 also includes a header 1204. The header 1204 typically includes a destination address 1206 that specifies the destination network element (or recipient) to which the data packet 1200 is to be routed. That is, the address 1206 specifies which central network 102, user network 104, 25 or peripheral network 105, or their lower level nodes is the designated recipient of the particular data packet 1200. When the recipients recognize their particular address 1206 in the data packet 1200, the recipients accept the payload 1202 appended to the address 1206.

The data packet 1200 also includes a cyclical redundancy check (CRC) 1208, that is used to detect errors in the transmission of the data packet

1200. Other forms of error detection and correction may be used in place of, or in addition to, the CRC 1208. The data packet 1200 may also include error correction data under any conventional error correction method. The data packet 1200 also includes a miscellaneous portion 1210 for miscellaneous control or 5 data information, such as for multicasting or broadcasting sessions. An illustrative data packet 1200 is a SONET data packet structure. An alternative is a standard Internet Protocol (IP) data packet, (e.g., IPv.4 (IPv.6) data packets with IEEE Ethernet 802.3 framing).

Sectorization

10 Recall that in one embodiment, data is sent from the central networks 102 to the user networks 104 using the light cones 106, and that the light cones 106 are shaped and diverging coherent light beams. Several shaped and diverging coherent light cones 106 are radiated in the substantially circular radiation pattern that illuminates any or all parts of the area surrounding the 15 central networks 102, much like a theatrical spotlight illuminates a stage. Parts of the illuminated areas can be emphasized, or made "brighter" than others, in order to deliver more signal strength to chosen areas. As is the case with the theatrical spotlight, the light cones 106 can be configured into any shape. The radiation pattern radii can be anywhere from one quarter meter to over three 20 kilometers.

Each central network 102 optically shapes the laser radiation patterns into the narrow radial sectors containing elevation sectors into which the wavelengths of infrared laser lights are transmitted. In one embodiment, the central downlink signal processor 206 shapes the laser beam into the desired 25 radiation pattern, with radial (or horizontal) sectors and/or elevation (or vertical) sectors further divided into several channels. Each channel is allocated particular wavelengths. A user can be assigned a wavelength such that the central networks 102 transmit a high-speed data stream to each user or group of users on the assigned wavelength. Each vertical sector and each horizontal sector may have

one or more channels of different wavelengths. Each of the channels may carry at least 10 Gbps of data. This arrangement accommodates a data transmitting capacity in excess of 20 Tbps and can service thousands of users.

Figure 13 illustrates an illustrative transmission point 1301 with 5 sectorization 1300. According to this embodiment, there are several horizontal subsectors, as represented by subsectors 1302a, 1302b and 1302c. Each sector may have vertical subsectors, as represented by subsectors 1306a and 1306b. Each vertical or horizontal subsector may be further divided into another subsector. Each horizontal subsector 1302a-c and/or vertical subsector 1306a-c 10 can have one or more wavelength channels (not shown).

When the communication system 100 communicates using the transmission point 1301 with the sectorization pattern 1300, the address in the data packet 1200 specifies the appropriate sector 1302 and wavelength channel.

It should be noted that the highly controllable shaped beams make 15 wavelength (or frequency) reuse a non-issue using the communication system 100. The sectors in the communication system 100 are strictly spatially separated, and so any channel can be used in any sector. This spatial reuse technique provides distinct advantages over common non-optical systems. Conventional frequency reuse schemes were necessary because of radiation 20 pattern side lobe interference caused by well-known right phrasing. Implementation of sectorization and shaped and diverging coherent light beams 106 avoids side lobe interference problems and, thus, avoids the need for frequency-reuse schemes. To accomplish this, the central transmit antennas 208 use central geometric antennas that are very large in terms of operating 25 wavelength (e.g., approximately eighty times the wavelength). Conversely, conventional radio antennas are approximately the same size as the carrier wavelength, so they cannot use geometric optics for their transmission sectors.

The transmission point 1301 with the sectorization pattern 1300 can generate several types of "footprints," as defined herein as an area of 30 coverage projected onto the buildings housing the user networks 104 by the beam

radiated from the transmission point 1301. In an embodiment, the transmission point 1301 has shaped sectorization designed to project a roughly circular footprint on the buildings housing the user networks 104.

Of course, the invention is not limited by the shape of the 5 footprints. Figure 14 illustrates examples of various suitable footprints 1402a-f generated by the central transmit antennas 208. While, in some cases, only one central transmit antenna 208 is illustrated per set of light cones 106 transmitted, it is to be understood that, for example, the central transmit antenna 208a includes 10 several telescopes, each capable of generating a uniquely shaped radiation pattern. For example, as one telescope of the central transmit antenna 208c generates a light cone 106d which produces a substantially circular footprint 1402d, another telescope of the central transmit antenna 208c generates a light cone (not shown) which produces a substantially heptagonal footprints 1402c.

Other footprints include elliptical, hexagonal, donut-shaped, 15 square, etc. For example, referring back to Figure 13, the subsector 1302a would generate an elliptical footprint. The subsector 1306a produces a hexagonal footprint. The subsector 1306b generates a donut-shaped footprint.

One purpose for overlapping radiation patterns is to deliver data at 20 different data rates or capacities to the same building. Of course, the particular radiation pattern used is determined by a number of factors, including the size and shape of the building that houses the user networks, for example, that ensure that the power in the optical signal is effectively utilized.

The communication system 100 also can include an optical repeater 1404, which receives, reconstructs, and amplifies either one way or 25 bidirectionally the light cones 106 and retransmits them to the user networks 104. The optical repeater 1404 compensates for dead spots in the transmitting radiation patterns. The optical repeater 1404 thus acts as an extension between central networks 102. The optical repeater 1404, while depicted as a single element, may contain multiple receiver-transmitter pairs that detect, reconstruct,

amplify, and retransmit the light cones 106 under the components discussed above with respect to Figures 2-6.

Figure 15 shows an illustrative topography 1500 surrounding the central networks 102, by the sectorization pattern 1300. The embodiment depicted in the topography 1500 includes three hexagonal light propagation patterns 1502a, 1502b, and 1502c. In this embodiment, each sectorization pattern 1300 has 36 sectors, where one sector in each sectorization pattern 1300 is represented by the sectors 1502a₁, 1502b₁, and 1502c₁, respectively. An alternative embodiment has 60 radial sectors, each with six degrees of azimuth, and five elevation sectors, each with eight channels accommodating a data rate from 10 Mbps to 10 Gbps. Still another embodiment divides a radiation pattern into 120 three-degree sectors, with each sector delivering 10 Mbps to 10 Gbps to the user networks 104.

Figure 15 also depicts several central networks 102 interconnected by ultra-wide bandwidth optical backbone links 1510. The optical backbone links 1510 also allow interconnection with Internet POPs, major carriers, the PSTN, or other peripheral networks 105.

The systems, methods, and interconnected devices for networked, high-speed bi-directional data communication through free space described herein are particularly suitable for use in foggy weather conditions, where optical signals are susceptible to attenuation. A study in London, England of point-to-point laser communication produced data on reliability that, when combined with a historical database, produced a weather database with forty years of data collected on an hourly basis. With this kind of information, the parameters of the communication system 100 can be modified to compensate for certain atmospheric conditions. For example, the power output of the central transmit antennas 208 and/or the user antennas 302, radii of the cells, sensitivity of the detectors and/or the data rate can be increased or decreased as appropriate. Similarly, the size of the antennas can be adjusted to compensate for any anticipated attenuation of the signal.

The coverage area of the radiation pattern generated by the central transmit antenna **208** also can be predetermined by design to anticipate atmospheric conditions. For example, in the city of Seattle, Washington which is known for foggy conditions typically causing strong attenuation, the radiation 5 patterns can be reduced to one quarter kilometer, as opposed to the two kilometer radiation patterns appropriate for sunny locations.

Other suitable modifications include changing the shape of the light cones **106**, changing the tint of the windows through which the light beams/light cones are transmitted, changing the optical amplifier strengths, etc.

10 Broadcast and Multicast Operation

Recall that the communication system **100** broadcasts and multicasts data from the central networks **102**. During broadcast operations, the data is transmitted from any one of the central networks **102** or their lower level nodes to all user networks **104** and/or all peripheral networks **105** and/or their 15 lower level nodes, for example. Any well-known broadcast addressing scheme is suitable for implementing this embodiment.

During point-to-multipoint multicast communication, selected user networks **104**, peripheral networks **105**, and/or their lower level nodes receive data. This embodiment is ideal in situations where identical data content is 20 desired to be transmitted to a particular group of user networks **104** and/or peripheral networks **105** substantially simultaneously (e.g., during video teleconferences).

In this embodiment, the miscellaneous portion **1210** of the data packet **1200**, depicted in Figure 12, includes a multicast session identifier (not 25 shown) that identifies a multicast session and a set of users that are the recipients of the transmission during the particular multicast session. The content of the transmission that one member of a multicast session group receives is substantially the same as the high-speed data that another member of the multicast session group receives during a particular multicast session.

Each multicast session identifier is associated with a set of unique addresses. There is a unique address for each recipient of the multicasted data. The central network **102** transmits the multicast session identifiers to the recipients, which use the association to determine the unique address for each of the recipients associated with the set of unique addresses. The central network **102** adds the unique addresses for the recipients to each data packet **1200** received from the other interconnected networks prior to transmitting the received data packet **1200** to the specified set of recipients.

Each central network **102** also may include a plurality of multicast session identifier translation tables to translate multicast session identifiers into unique addresses for the subscribers. There may be one or more multicast sessions identified by multicast session identifiers. Each of the multicast session identifiers is associated with a set of unique addresses representing a set of users. The central network **102** includes at least one translation table to correlate the multisession identifiers with each set of unique addresses for the set of selected recipients.

Table 1 is an example of a multicast session identifier table suitable for use with one embodiment of the invention. Table 1 lists example multicast sessions (1 through 4), functional group identifiers (A through D) for the functional groups associated with a particular multicast session, sets of addresses for the particular recipients in the particular functional group, and recipients associated with the unique addresses designated to receive transmissions during the particular multicast session. Note that the multicast sessions may have overlapping recipients such that one recipient may be included in the multicast session "1" as well as in the multicast session "2." Note that the recipients are designated **104a** through **104d** to represent either several user networks **104** or several of their lower level nodes.

Table 1

| Multicast Session | Functional Group ID | Unique Addresses | Recipients |
|-------------------|---------------------|--|------------------------------|
| 1 | A | 0112.3456.7890 0223.4567.8901 0334.5678.9012 0445.6789.0123 | 104a 104b 104c 104d |
| 2 | B | 0445.6789.0123 0223.4567.8901 0334.5678.9012 | 104d 104b 104c |
| 3 | C | 0445.6789.0123 0112.3456.7890 | 104d 104a |
| 4 | D | 0445.6789.0123 0334.5678.9012 | 104d 104c |

Figure 16 is a flowchart showing an illustrative multicast process 1600. The multicast process 1600 starts at step 1602, where control immediately 5 passes to step 1604. In step 1604, one of the peripheral networks 105 transmits high-speed data and a multicast session identifier to the central network 102. For example, according to Table 1, during the first multicast session, one of the peripheral networks 105 transmits the functional group identifier "A" to the central network 102.

10 In step 1606, the central network 102 receives the high-speed data and the multicast session identifier. In step 1608, the central network 102 determines the functional group associated with the multicast session by looking in its translation table. In step 1610, the central network 102 determines the set of recipients in the functional group.

15 In step 1612, the central network 102 determines the unique address of each recipient in the set of recipients in the functional group. For example, the central network 102 looks in its multicast session identifier translation table to determine the unique address for the sets of recipients associated with the functional group identifier "A." In step 1614, the central network 102 adds the unique address for the sets of recipients to the high-speed data received from the central network 102 and transmits the resulting high-speed data to the recipients 104a-d. Once the high-speed data has been transmitted 20

from the central network **102** to the recipients **104a-d**, the multicast process **1600** ends, as indicated by step **1616**.

It is noted that the multiplexing and demultiplexing schemes used by the central networks **102** differ from the multiplexing and demultiplexing schemes used by the user networks **104** in that the central networks' **102** multiplexing and demultiplexing schemes have additional levels of address translation to accommodate routing of incoming IP addresses to the appropriate addressees. The additional routing is implemented in the central router/switcher **204**.

All of the optics described herein can be enclosed in a "black box," such as a Faraday cage, to isolate the optical components from outside interference such as extraneous optical frequencies. Enclosing the optics in a black box is less expensive and simpler than conventional methods for eliminating outside interference.

Recall that the central router/switcher **204** connects the central network **102** to the peripheral networks **105** and to the user networks **104**, enabling data to be exchanged between them. Recall further that the central router/switcher **204** supports NICs implemented in a G-NIC Network Interface Card available from Packet Engines. Figure 17 shows an illustrative central router/switcher **204** implemented on the G-NIC Network Interface Card.

The central router/switcher **204** in this embodiment includes a gigabit uplink port **1702** and up to two server ports: an optional gigabit server port **1704** and a 10/100 Ethernet server port **1706**. The central router/switcher **204** also includes a glue logic and memory control processor **1707**. The gigabit uplink port **1702** receives data packets **1200** on its input and sends the data packets **1200** to the output of whichever server port is active. At the same time, the central router/switcher **204** sends any data packets **1200** received on an input of the active server port to the output of the gigabit up link port **1702**.

It is noted that all data packets **1200** coming from either server port **1704, 1706** will be sent to the gigabit uplink port **1702**, but the data packets **1200**

coming from the gigabit uplink port 1702 destined for either server port 1704, 1706 will be filtered by the glue logic and memory control processor 1707. That is, only the data packets 1200 meeting the filter requirements will be sent to the appropriate server port 1704, 1706. At a minimum, the gigabit uplink port 1702 5 filters received data packets 1200 by accepting only the data packets 1200 destined for a particular Ethernet address. In this embodiment, the gigabit uplink port 1702 also accept broadcast data packets and multicast data packets. In one embodiment, filtering may be performed by a host computer system under the purview of a user network 104.

10 The central router/switcher 204 in another embodiment is connected from one of the server ports directly to a matching port on a host computer system located at a user network 104. In this embodiment, if the gigabit uplink port 1702 uses the same Ethernet address as the port on the host computer system, the central router/switcher 204 supports only that host on its 15 gigabit uplink port 1702. This is because the Ethernet address of the host computer system is programmed into the central router/switcher 204.

20 In another embodiment, the central router/switcher 204 "auto-discovers" its Ethernet address from the data packets 1200 seen on the server ports. Alternatively, central router/switcher 204 is preprogrammed with the same Ethernet address as an Ethernet card assigned to the host computer system.

Some Additional Features

25 The communication system 100 increases both the transmit and receive communication capacity of conventional communication systems. The greater capacity is important to note because standard telephone lines are being pushed to their limit and can provide only approximately 60 Kbps of data network connection. Other network alternatives have been developed but have their limitations as well. For example, ISDN, once thought to be the wide area networking solution of choice, is limited to 128 Kbps. The newly touted ADSL services are limited to eight Mbps and are asymmetric (fast in only one

direction—the downlink). Existing personal computers (PCs) have the ability to network locally at over 100 Mbps, leaving these wide area network technologies extremely inadequate.

5 The most publicized attempt to break the bandwidth bottleneck incorporates satellites in low-Earth orbits (LEO). These satellite networks can obtain data down-link rates from 1.5-28 Mbps. The cost to deploy these systems, however, ranges into billions of dollars and requires years to deploy.

10 Fiber optic and LMDS are also available and planned technologies in the telecommunication market. While LMDS is thought to require only 25 percent of the capital cost of deploying optical fiber, there appears to be an upper limit from four to six Gbps of total traffic capacity per four kilometer wide cell, which places a significant limit on system growth. For example, in an area twice the size of downtown Seattle's business core, only 40 to 60 concurrent customers could have 100 Mbps access. In contrast, the optical communication system 100 15 can potentially serve up to thousands of such concurrent connections.

20 The communication system 100 may only require 30 percent of the capital cost of an LMDS (or approximately eight percent of fiber) without the two Gbps limitation of total capacity per cell. Recall that the communication system 100 has the ability to communicate at 2.5 Gbps duplex or 1.25 simplex per channel, and its overall capacity per system may be in excess of two Tbps. This capacity is 1,000 times higher than LMDS and translates to significantly lower infrastructure costs, and the ability to undercut competitors' pricing and/or outperform competitive offerings.

25 The communication system 100 accomplishes these staggering speeds/volumes by combining wireless, fiber, and networking concepts to form a unique network that has the ability to deliver terabits of information around the world in a very timely and cost-efficient manner.

The communication system 100 antennas are similar in size and shape to a small dish antenna of the type that can be found on many rooftops.

However, the antennas may be placed behind a window glass, making deployment much easier than rooftop-only installations.

While the technology that the communication system 100 implements allows for a radiation pattern radii well over three kilometers, for 5 urban cores, however, the central networks 102 can be much smaller and dependent upon the geography of the region as well as the building size and building location. Moreover, as described above, the communication system 100 has a very advantageous channel re-use property, allowing significantly lower costs, significantly higher capacities, and greater bandwidth.

10 Using a very simple example, assume one central network 102 is sectored into 120 three-degree sectors, with each sector delivering 100 Mbps to 2.5 Gbps. In this very simple example, this single central network 102 has the ability to deliver 300 Gbps to a large number of users. With the addition of additional channels per sector, the data throughput increases significantly. By 15 using eight channels per sector, the optical communication system 100 has the ability to effectively increase the data throughput on a single local central network 102 to 2.4 Tbps. Such a central network 102 could supply 100 Mbps service to 24,000 concurrent users. This far exceeds conventional communication systems. The only close competitor is LMDS, which currently is 20 limited to about four Gbps per cell site.

Many of the components in the communication system 100 may be implemented using hardware, software, or a combination of hardware and software, and may be implemented in a computer system or other processing system. In aspects where the invention is implemented using hardware, the 25 hardware components may be Application-Specific Integrated Circuits (ASICs), or a hardware state machine. In aspects that are implemented using software, the software may be stored on a computer program product (such as an optical disk, a magnetic disk, a floppy disk, etc.) or a program storage device (such as an optical disk drive, a magnetic disk drive, a floppy disk drive, etc.). That is, 30 software may be available from a removable disk or from code downloaded on a

hard drive. Moreover, the software can include code stored in a module such as a Read-Only Memory (ROM), Programmable ROM (PROM), or any variation of an Erasable PROM (*e.g.*, EPROM, EEPROM, etc.).

According to one embodiment, the communication system 100 uses 5 well-known Time Division Multiple Access (TDMA) techniques. In TDMA, each user network 104 is assigned one or more TDMA time slots based on the allocated wavelength (or data rate), and the networks communicate with each other during the designated TDMA time slots. When the communication system 100 uses TDMA technology, the communication system 100 can multiplex 10 several user networks 104 on one TDMA channel, using a well-known diffraction grading (or pattern mask) to receive only certain bits from the data stream for each user network 104.

A resource manager (not shown) coordinates assignments of TDMA time slots. The resource manager negotiates for a channel (*e.g.*, a time 15 slot at a particular frequency).

Interconnection of the arrangement of the light cones 106 and the collimated light beams 108 may be done using standard Internet protocols, such as "open shortest path first" (OSPF), which is a link state routing algorithm that is used to calculate routes based on the number of routers, transmission speed, 20 delays, and route costs. Interconnection of the light cones 106 and the collimated light beams 108 can also be accomplished using other well-known routing algorithms.

Figure 18 shows an alternative embodiment of the communication system 100. This alternative embodiment uses a multi-access 25 receiver/transmitter (MART) 1802 for both transmission and reception. The central network 102 is connected to the MART 1802 by a transmission link 1800. The transmission link 1800 is a hardwire link, such as a telephone line or fiber optic cable, but it is also possible to use a wireless link (*e.g.*, radio frequency, laser light, etc.). Additionally, while Figure 18 depicts the central network 102

and the MART 1802 as being separated, remote components, it is appreciated that the MART 1802 can be within the central network 102.

The MART 1802 includes an array 1804 of central transmit antennas 208 and central receive antennas 802. The central transmit antennas 208 in Figure 18 are coaxially located at the center of their respective central receive antennas 802. Other modifications are possible. For instance, the central transmit antennas 208 may be located near (e.g., separated from) their respective central receive antennas 802, instead of being coaxially located. It is also possible to use the same optical device to transmit and receive if wavelength separation between the transmitted and received signals is adequate.

Downlink transmission from the central network 102 to the user network 104 and/or the peripheral network 105 uses a concept of splitting a single broadcast beam into several light cones 106, with each light cone 106 having all of the information present in the single broadcast beam. First, one or 15 more power amplifiers 408, such as a 500 mW EDFA, in the MART 1802 splits the single broadcast beam received through the transmission link 1800 and provides the individual signals to respective central transmit antennas 208. The central transmit antennas 208 then transmit the individual signals as light cones 106 to the user network 104 and/or the peripheral network 105. The array 1804, 20 or the individual central transmit antennas 208 and central receive antennas 802, can be mounted, for example, onto one or more gimbal structures to direct the transmitted light cones 106. Available optics are used to focus and direct the light cones 106 as necessary.

The embodiment shown in Figure 18 allows one or more light 25 cones 106 to be focused on particular receivers in the user network 104 or the peripheral network 105. That is, instead of transmitting to an entire building, separate light cones 106 can be transmitted to particular receivers in the building. Further, the separate light cones 106 can have different power, such that light cones 106 having greater power are transmitted to receivers that are farther away 30 or are behind darkly tinted windows, and light cones 106 having less power are

transmitted to closer-range receivers. Also, the MART 1802 can transmit to more than one building, such that some light cones 106 are transmitted to one building and other light cones 106 are transmitted to other buildings. By adjusting the power level of the transmission and pointing the central transmit 5 antennas 208 in the appropriate direction, it is thus possible to "link" several buildings and at greater distances from the same MART 1802. To maximize efficiency, a given power output of the power amplifier 408 can be apportioned between the various light cones 106, such that light cones 106 requiring less power are reduced in power while the other light cones 106 requiring more 10 power are correspondingly increased in power.

Further, the scope of transmission coverage of the MART 1802 is easily changed by adjusting the number of splits in the power amplifier 408. A sector of up to a full hemisphere is possible by splitting a single broadcast signal with the power amplifier 408 and providing central transmit antennas 208 in each 15 quadrant.

The MART 1802 can also receive collimated light beams 108 from the user network 104 and/or peripheral network 105. A plurality of collimated light beams 108 transmitted from individual transmitters in the user network 104 and/or the peripheral network 105 are received by the central receive antennas 20 802 in the MART 1802. Like the transmission from the MART 1802 described above, the uplink transmission of collimated light beams 108 from the user network 104 and/or the peripheral network 105 to the MART 1802 allows multiple signals to be linked at the MART 1802.

Many possible design parameters can be used for the embodiment 25 shown in Figure 18. For instance, a 12° sector can project a light cone 106 of 100 meters in diameter at a distance of 500 meters. A three mrad beam can project a light cone 106 having a diameter of 1.5 meters at a distance of 500 meters. Using the same transmit power and assuming zero losses during the split, a three mrad beam can be projected at each of 4,444 customers and have the 30 same power density as the 12° sector. Alternatively, service can be provided to

100 customers, with a 16 dB of link margin for each. The increased link margin can be used to reduce the size and costs of each customer's receiver.

Although specific aspects of, and examples for the invention are described herein for illustrative purposes, various equivalent modifications are possible within the scope of the invention and can be made without deviating from the spirit and scope of the invention, as will be recognized by those skilled in the relevant art. For instance, although a laser has been described herein as generating the various light beams and light transmissions, other light-generating devices, such as light-emitting diodes (LEDs), can be used. Also, although the 10 collimated light beams 108 are used in the network uplink components (*see, e.g.*, Figures 7-10) and the light cones 106 are used in the network downlink components (*see, e.g.*, Figures 2 and 3-5) in the embodiments described herein, it is to be appreciated that in some embodiments, the network uplink components can use the light cones 106 or the network downlink components can use the 15 collimated light beams 108. Further, several channels (*e.g.*, frequency domain) can be used in the uplink as well, with appropriate coordination between a user and a central node.

The teachings provided herein of embodiments of the invention can be applied to optical links made functional by any standard network 20 interconnection. For example, the G-NIC Network Interface Card (*see, e.g.*, Figure 2) can be implemented in PCs. Further, one or more components or functions of the communication system 100 can be embodied in a computer network, computer-readable media (such as magnetic cassettes, digital video disks, CD-ROMs, Bernoulli cartridges, random access memories (RAM), ROMs, 25 smart cards, etc.) and their associated devices. One or more components or functions of the communication system 100 can be embodied in computer-readable or computer-executable instructions such as program modules or macros executable by a microprocessor or by a computer. How to implement these types of features can be understood by one skilled in the art based on the detailed 30 description provided herein.

These and other changes can be made to the invention in light of the above-detailed description. In general, in the following claims, the terms used should not be construed to limit the invention to the specific aspects disclosed in the specification and claims, but should be construed to include all 5 optical communication systems that operate under the claims to provide, *inter alia*, high-speed optical data communication. Accordingly, the invention is not limited by the disclosure, but instead the scope of the invention is to be determined entirely by the following claims, which are to be construed in accordance with established doctrines of claim interpretation.

CLAIMS

What is claimed is:

1. A communication system, comprising:
 - a peripheral node configured to transmit at least one first information signal and configured to receive a second information signal;
 - at least one central node configured to receive the first information signal from the peripheral node and transmit the received first information signal through free space modulated on a first light beam, configured to transmit the second information signal to the peripheral node, and configured to receive at least one third information signal from free space modulated on a second light beam; and
 - at least one user node configured to receive the first light beam and demodulate the modulated first information signal from free space, and configured to transmit the third information signal through free space modulated on the second light beam.
2. The communication system of claim 1 wherein the first light beam comprises a shaped and diverging laser beam and the second light beam comprises a collimated light beam.
3. The communication system of claim 1 wherein the at least one central node includes:
 - a plurality of central nodes forming a central network, each central node configured to transmit a plurality of the first information signals modulated on shaped and diverging coherent light beams through free space; and
 - wherein the at least one user node includes a plurality of user nodes forming a user network, each user node configured to receive the plurality of first information signals modulated on shaped and diverging coherent light beams through free space. and

wherein the central nodes are configured to transmit to the user nodes in a node-to-node, node-to-multipoint, multipoint-to-node, or multipoint-to-multipoint manner.

4. A method for transmitting data between a central point and at least one user, the method comprising:

at the central point, modulating data and at least one user address on a light beam;

at the central point, transmitting the light beam through free space;

demodulating the light beam and retrieving the data and the at least one user address;

routing the data to the user according to the user address; and
transmitting data from the user to a central point.

5. The method of claim 4 wherein the light beam on which the data and the at least one user address is modulated comprises a shaped and diverging light beam.

6. The method of claim 4 wherein the light beam on which the data and the at least one user address is modulated comprises a shaped, diverging, and coherent light beam.

7. The method of claim 4 wherein the light beam on which the data and the at least one user address is modulated comprises a laser beam.

8. The method of claim 4, further comprising:

modulating the data and several user addresses on a light beam;

routing the data to the several user addresses; and

transmitting data from at least one of the users to a central point through free space or via at least one telephone line.

9. The method of claim 4, further comprising transmitting the light beam through free space to several user addresses in a point-to-point, point-to-multipoint, multipoint-to-point, or multipoint-to-multipoint manner.

10. A communication system, comprising:
a central node configured to transmit through free space an information signal modulated on a diverging coherent light beam; and
a user node configured to receive from free space the diverging coherent light beam and automatically process the modulated informational signal, wherein the diverging coherent light beam, as received at the user node, has different dimensions diverging coherent light beam at the central node.

11. The communication system of claim 10, further comprising:
a plurality of central nodes each configured to transmit through free space a plurality of information signals modulated on a plurality of diverging light beams; and
a plurality of user nodes each configured to receive from free space the informational signals modulated on diverging light beams, wherein the central nodes are configured to transmit to the user nodes in a broadcast, simulcast, or multicast manner.

12. The communication system of claim 10 wherein the central node is configured to transmit through free space to the user node in one of a broadcast or multicast manner.

13. The communication system of claim 10, further comprising a peripheral node configured to transmit the information signal to the central node for modulation.

14. The communication system of claim 10, further comprising a common carrier, virtual node, or an area node configured to transmit the informational signal to the central node for modulation.

15. The communication system of claim 10 wherein the central node and the user node are interconnected using synchronous optical network (SONET) architectures.

16. The communication system of claim 10, further comprising a peripheral node, wherein the central node, user node, and peripheral node are interconnected using synchronous optical network (SONET) architectures.

17. The communication system of claim 10 wherein the central node and the user node are interconnected using gigabit Ethernet architectures.

18. The communication system of claim 10, further comprising a peripheral node, wherein the central node, user node, and peripheral node are interconnected using gigabit Ethernet architectures.

19. The communication system of claim 10 wherein the diverging light beam comprises a shaped, coherent infrared laser operating at a wavelength of approximately 1550nm.

20. The communication system of claim 10 wherein the diverging light beam comprises a shaped coherent infrared, near-infrared, or visible light laser beam.

21. The communication system of claim 10 wherein the light beam comprises a shaped and coherent diverging light beam.

22. The communication system of claim 10, further comprising a diffraction grating, beam shaping lens, or a holographic optical element.

23. The communication system of claim 10, further comprising a beam shaping optic that horizontally shapes the diverging light beam.

24. The communication system of claim 10, further comprising a beam shaping optic that vertically shapes the diverging light beam.

25. The communication system of claim 10 wherein the information signal further comprises at least one data packet having a header and a payload, the header specifying at least one of the user nodes and the payload comprising high-bandwidth data.

26. A communication system, comprising:

at least one user node configured to transmit an information signal through free space modulated on a light beam; and

a central node configured to receive the light beam from free space and to demodulate the information signal from the light beam, and to send the information signal to a peripheral node.

27. The communication system of claim 26 wherein the light beam comprises a collimated light beam.

28. The communication system of claim 26 wherein the light beam comprises a shaped and diverging light beam.

29. The communication system of claim 26 wherein the user node is configured to transmit the information signal modulated on a collimated laser beam

and the central node is configured to receive the information signal modulated on a collimated laser beam.

30. The communication system of claim 26 wherein the user node further comprises an antenna having a diffraction grating, beam shaping lens, or a holographic optical element.

31. The communication system of claim 26 wherein the light beam comprises a light beam in a substantially 1550 nm region of a light spectrum.

32. An apparatus configured to transmit an optical carrier through free space to a plurality of user nodes, comprising:

- an input port configured to receive an information signal;
- a radiant energy generator configured to generate an optical carrier;
- a signal processor, coupled to the radiant energy generator and the input port, configured to process and combine the optical carrier with the information signal; and

- an antenna, coupled to the signal processor, configured to produce a shaped and diverging radiant energy and to transmit the combined optical carrier and information signal on the shaped and diverging radiant energy into free space.

33. The communication system of claim 32, further comprising a multiplexer configured to combine several information signals from several wavelength channels into the optical carrier.

34. The communication system of claim 32, further comprising an optical time division multiplexer (OTDM), high density wavelength division multiplexers (HDWDM), a coherent multi-channel heterodyne detector, a coherent multi-channel homodyne detector, a fused filter coupler, a Soliton multiplexer, a frequency combiner, a polarity combiner, a spatial combiner, or an algebraic transform

combiner configured to combine several information signals from several channels into the optical carrier.

35. The communication system of claim 32, further comprising a power amplifier, an erbium-doped fiber amplifier, or a ytterbium-doped fiber amplifier configured to amplify the optical carrier.

36. The communication system of claim 32, further comprising an encoder configured to encode data and control signals into the information signal.

37. A method for transmitting and receiving data between a user point and one of a plurality of peripheral points via a central point, the method comprising:

at the user point, modulating data and at least one peripheral point address on a collimated light beam;

at the user point, transmitting the collimated light beam through free space to the central point;

at the central point, demodulating the collimated light beam and retrieving the data and the peripheral point address; and

routing the data to the peripheral point address.

38. The method of claim 37, further comprising modulating the data and the peripheral point address on a collimated laser beam.

39. The method of claim 37, further comprising:

modulating the data and several peripheral point address on several collimated light beams; and

routing the data to the several peripheral point addresses.

40. The method of claim 37, further comprising transmitting the light beams through free space to the peripheral points in a point-to-point, multipoint-to-point, or multipoint-to-multipoint manner.

41. A method for transmitting data, comprising:
combining several data channels into a data stream;
modulating the data stream on at least one diverging light beam;
transmitting the diverging light beam through free space;
demodulating the diverging light beam and retrieving the data stream;

and

separating the several channels of data from the data stream.

42. The method of claim 41, further comprising:
modulating the data stream on a shaped and diverging light beam; and
routing the several data channels to several user devices.

43. The method of claim 41, further comprising modulating the data stream on a shaped, diverging, and coherent light beam.

44. The method of claim 41, further comprising modulating the data stream on at least two laser beams having different wavelengths transmitted over substantially a same diverging cone through free space.

45. The method of claim 41, further comprising transmitting the diverging light beam through free space to several users in a point-to-point, point-to-multipoint, multipoint-to-point, or multipoint-to-multipoint manner.

46. The method of claim 41, further comprising encrypting data on several data channels.

47. The method of claim 41, further comprising encoding data on several data channels.

48. An apparatus for receiving an information signal, comprising: an antenna configured to receive from free space an optical carrier having an information signal modulated on a shaped and diverging coherent light beam;

a signal processor, coupled to the antenna, configured to process and demodulate the shaped and diverging coherent light beam to separate the information signal from the optical carrier; and

an output port, coupled to the signal processor, configured to send the information signal to at least one device.

49. The communication system of claim 48 wherein the antenna includes at least one holographic optical element or a telescope.

50. The communication system of claim 48 wherein the signal processor includes at least one shaped and diverging coherent light beam detector, a demodulator, a demultiplexer, or a decoder.

51. The communication system of claim 48 wherein the interface is configured to send the informational signal to one of a signaling node management protocol (SNMP) device, a transmission control protocol (TCP) device, a gateway, a local area node, a bridge, a printer, a hard disk drive, a graphical display adapter, a television, a television set top box, telecommunication equipment, video conferencing equipment, audio/visual equipment, or home theater electronics.

52. A method of transmitting and receiving data, comprising:
receiving encoded data and a multicasting session identifier, the multicasting session identifier indicating a group of recipient user points selected from among a plurality of user nodes configured to receive the encoded data;
transmitting the encoded data and a multicasting session identifier on a shaped and diverging light beam via free space to the plurality of user nodes;
receiving the shaped and diverging light beam from free space; and
decoding the encoded data.

53. The method of claim 52, further comprising appending to the encoded data a group of unique user node addresses respectively representing the group of recipient user nodes.

54. The method of claim 52, further comprising modulating the encoded data and the group of unique user node addresses on a shaped and diverging light beam.

55. A data communication system, comprising:
a transmitter configured to transmit an informational signal through free space modulated on a shaped and diverging coherent light beam, wherein the coherent light beam is sufficiently divergent to be received by a plurality of spatially separated receivers; and
a set of receivers, selected from among the plurality of receivers, configured to receive the shaped and diverging coherent light beam from free space and decode the modulated informational signal.

56. The system of claim 55 wherein each receiver in the set of receivers has a unique receiver address and the transmitter is configured to add the unique receiver address to the informational signal before transmitting informational signal to the set of receivers.

57. The system of claim 55 wherein the transmitter is configured to transmit the informational signal using data packets having a multicasting session identifier associated with high-speed data and a set of selected receivers.

58. The system of claim 55, further comprising a storage device, coupled to the transmitter, configured to store a multicasting session identifier translation table to translate first and second multicasting session identifiers into unique receiver addresses of first and second sets of receivers, respectively.

59. A method for free space optical data communication, comprising:
receiving at an antenna, a shaped and diverging coherent light beam transmitted through free space, wherein the light beam has an information signal modulated thereon, and wherein a cross-sectional area of the received diverging coherent light beam as received at the antenna is substantially greater than an area of the antenna; and

demodulating and recovering the information signal from the shaped and diverging coherent light beam.

60. The method of claim 59 wherein the information signals comprises at least one video signal, audio signal or data signal.

61. The method of claim 59 wherein the high-speed information signals comprises at least one video signal at a first data rate, an audio signal at a second data rate, or a data signal at a third data rate.

62. A data communication system, comprising:
a transmission node having at least one radiant energy generator that generates information bearing radiant energy beams over several sectors,
wherein each subsector comprises a channel, and

wherein each channel operates at substantially the same wavelength.

63. The data communication system of claim 62 wherein the sectors comprise radial sectors.

64. The data communication system of claim 62 wherein the sectors comprise elevation sectors.

65. The data communication system of claim 62 wherein the sectors comprise radial sectors, wherein each sector includes at least two subsectors, and wherein the subsectors comprise elevation subsectors.

66. The data communication system of claim 62 wherein the sectors include at least one elliptically-shaped sector, hexagon-shaped sector, donut-shaped sector, elliptically-shaped subsector, hexagon-shaped subsector, or donut-shaped subsector.

67. The data communication system of claim 62 wherein each channel operates approximately at a 1550nm wavelength.

68. The data communication system of claim 62 wherein a first channel operates at a first wavelength and a second channel operates at a second wavelength.

69. The data communication system of claim 62 wherein the transmission node comprises a telescope.

70. A method of transmitting data comprising:
modulating at least one information signal on at least one carrier; and

substantially simultaneously transmitting the modulated information signal along a plurality of vertically differentiated sectors.

71. The method of transmitting data of claim 70, further comprising substantially simultaneously transmitting the modulated information signal along a plurality of horizontally differentiated sectors.

72. The method of transmitting data of claim 70, further comprising transmitting a plurality of channel wavelengths over each of the plurality of vertically differentiated sectors.

73. The method of transmitting data of claim 70 wherein at least two of the plurality of vertically differentiated sectors have differing cross-sectional beam shapes.

74. The method of transmitting data of claim 70 wherein each of the plurality of vertically differentiated sectors includes information modulated at the same wavelength.

75. The method of transmitting data of claim 70 wherein the at least one carrier comprises a plurality of diverging coherent light beams transmitted along the plurality of vertically differentiated sectors.

76. A communication system, comprising:
a central node configured to split an input signal into a plurality of substantially similar output signals;
a plurality of transmitters disposed in the central node to transmit the plurality of output signals to a user node as light signals; and
a plurality of receivers disposed in the central node to receive a plurality of user signals from the user node.

77. The system of claim 76 wherein the plurality of user signals comprise light signals.

78. The system of claim 76 wherein the plurality of output signals comprise a substantially same information content as the input signal.

79. An apparatus, comprising:

an amplifier having an input port to receive an input signal and operable to divide the input signal into a plurality of output signals;
a plurality of transmitters to transmit the plurality of output signals; and
a plurality of receivers associated with respective plurality of transmitters to receive user signals.

80. The apparatus of claim 79 wherein the output signals and user signals comprise light signals.

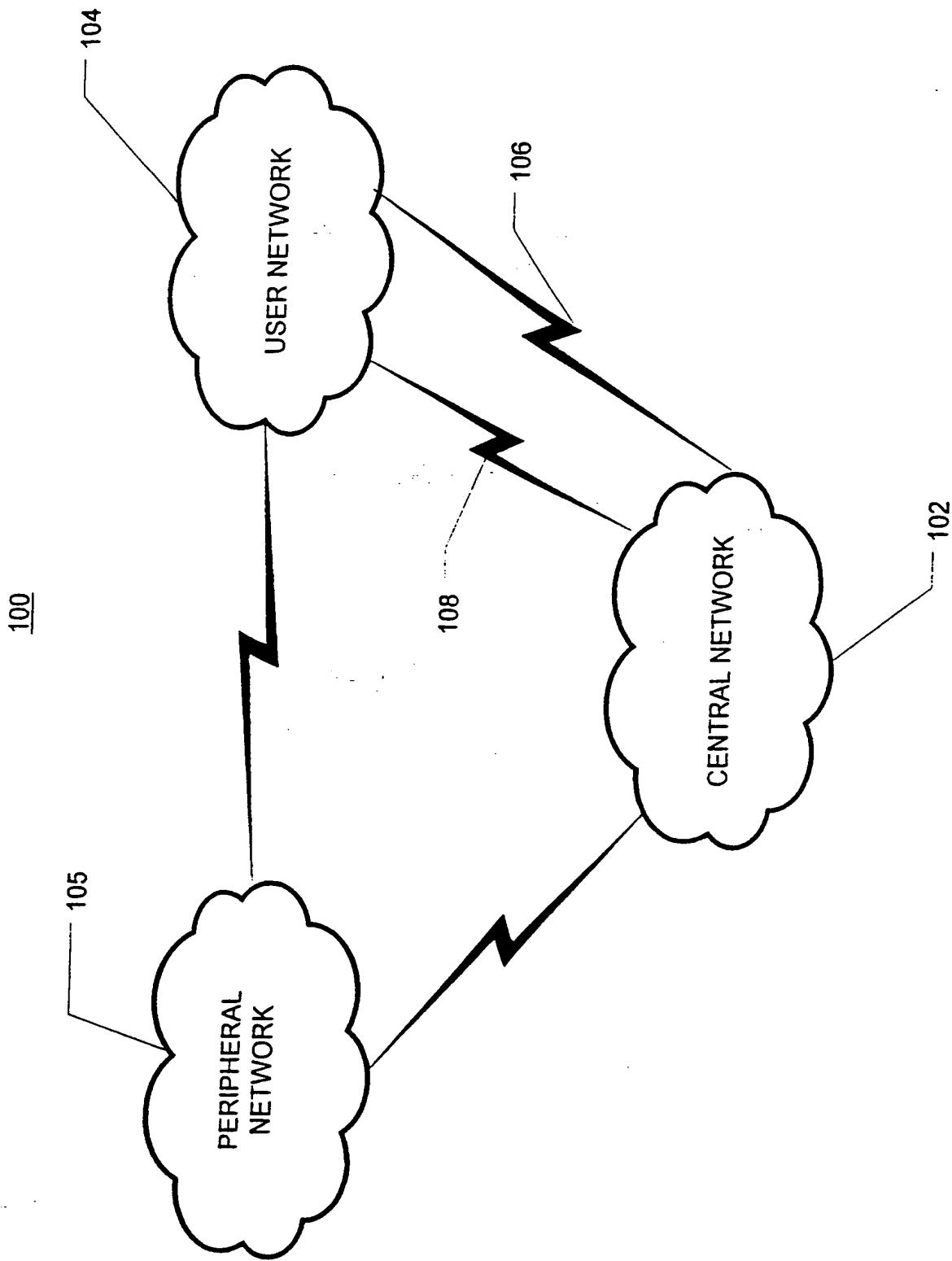
81. The apparatus of claim 79 wherein the plurality of output signals comprise a substantially same information content as the input signal.

82. A method of transmitting and receiving, the method comprising:
dividing an input signal into a plurality of output signals;
transmitting the plurality of output signals to a plurality of corresponding receivers of a user node; and
receiving a plurality of user signals transmitted from the user node light signals.

83. The method of claim 82 wherein transmitting the plurality of output signals comprises transmitting light signals.

84. The method of claim 82, further comprising providing each of the plurality of output signals with a substantially same information content as the input signal.

FIGURE 1A



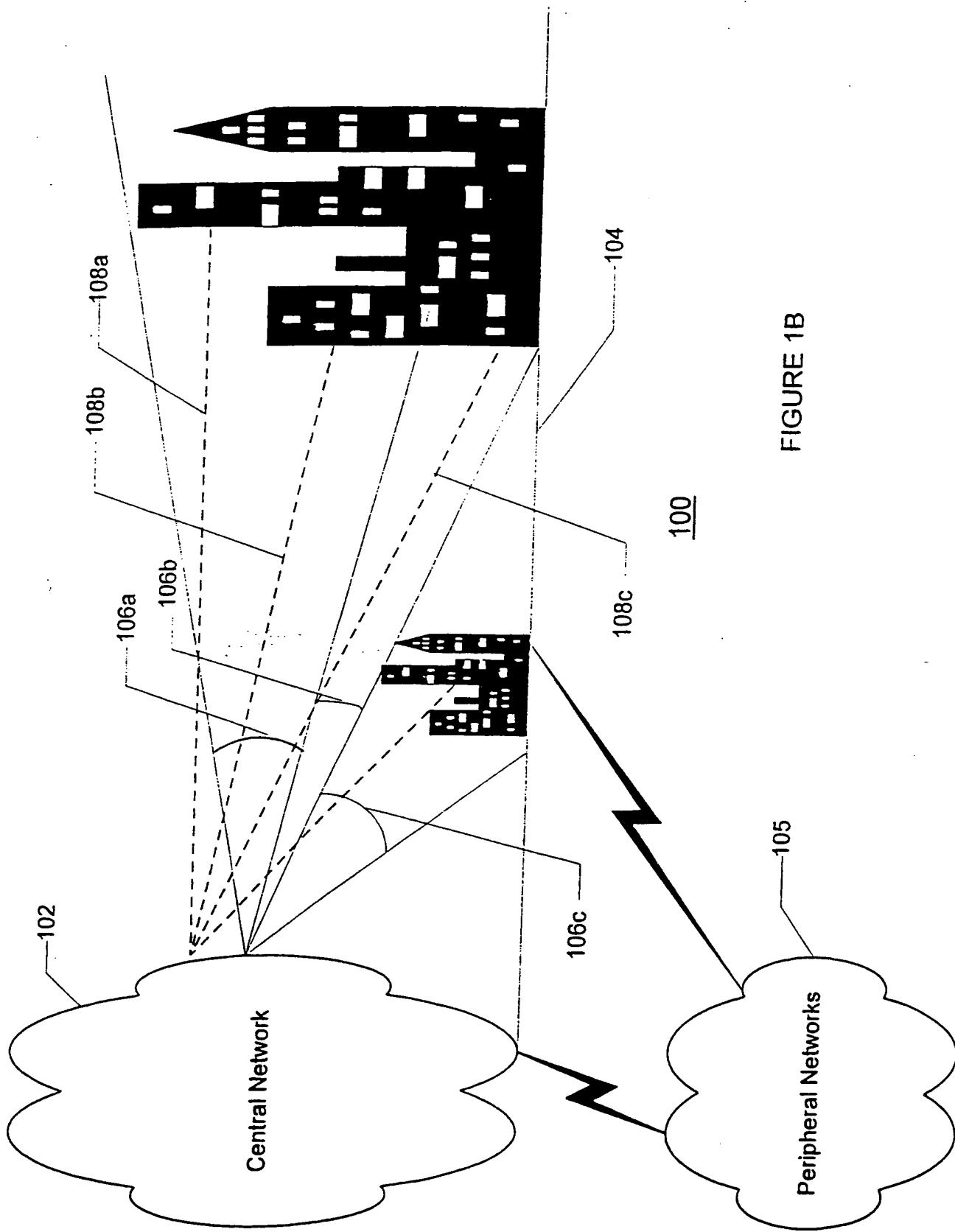
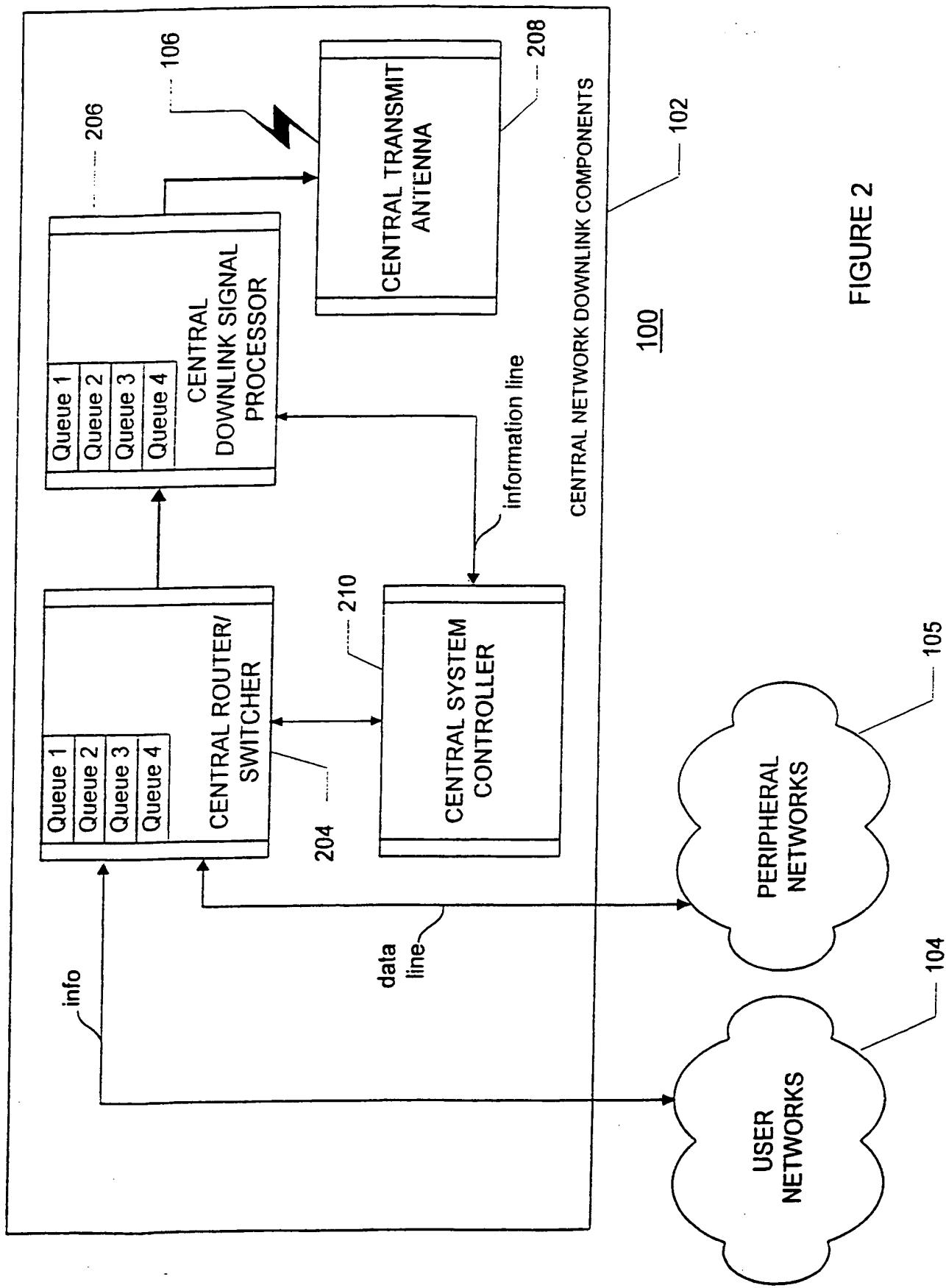


FIGURE 1B



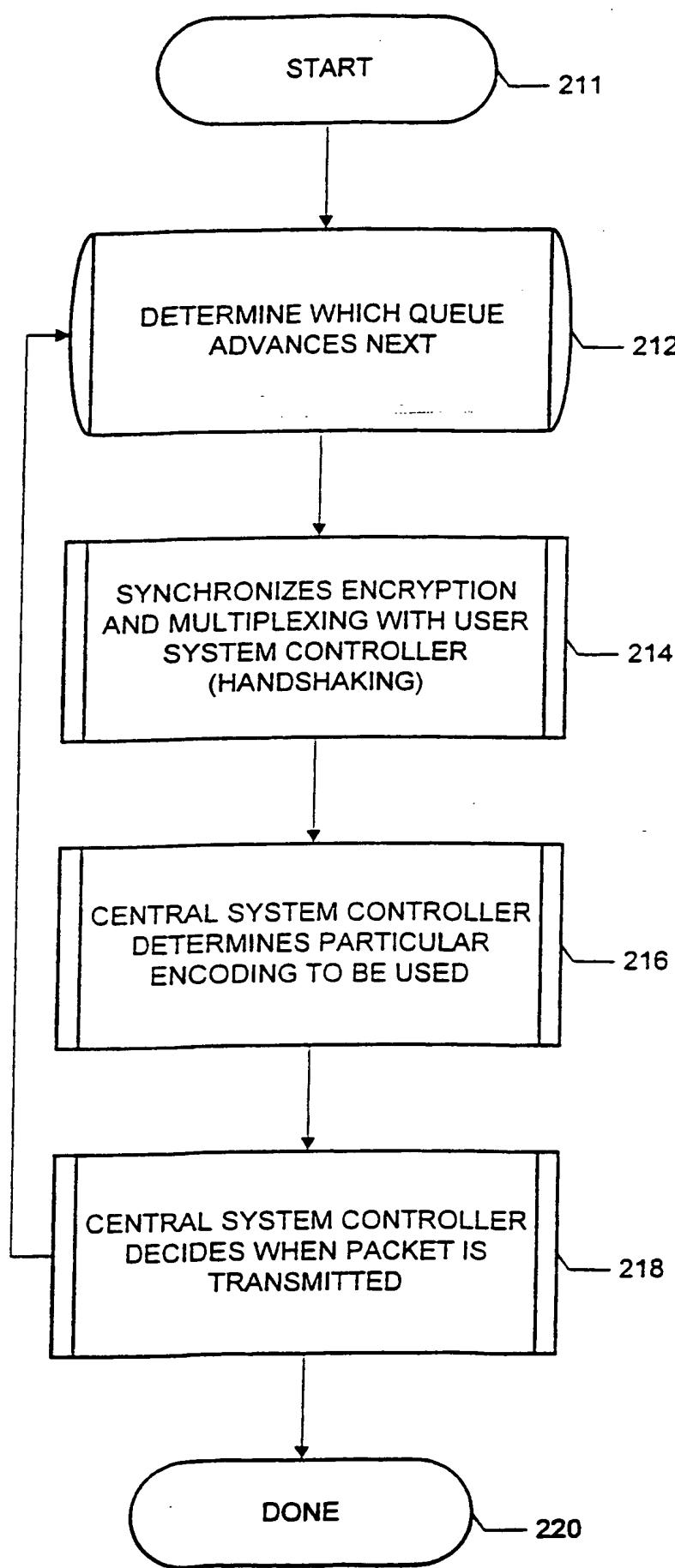
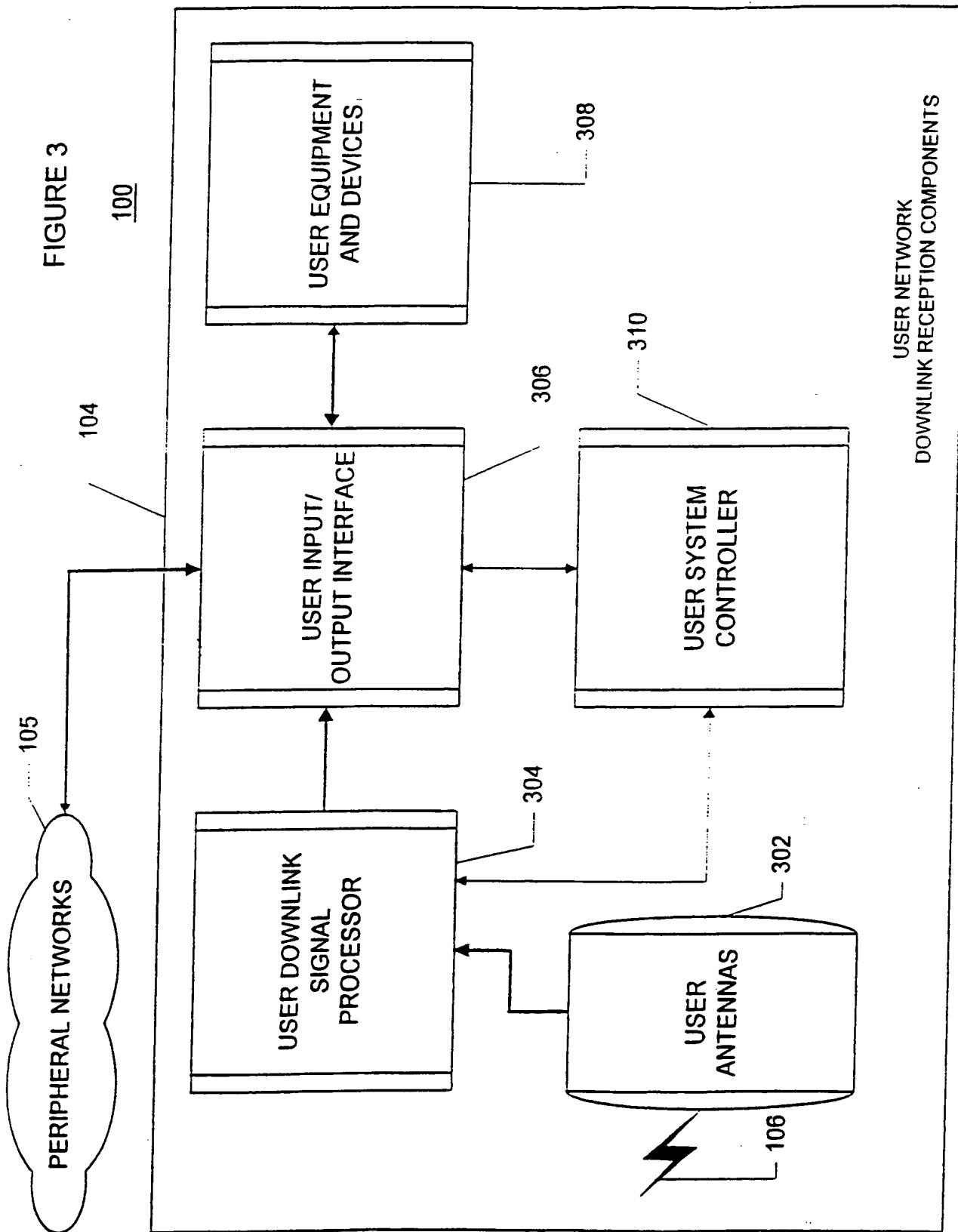


FIGURE 2A

CENTRAL
SYSTEM
CONTROLLER
TRANSMIT
FUNCTION
200



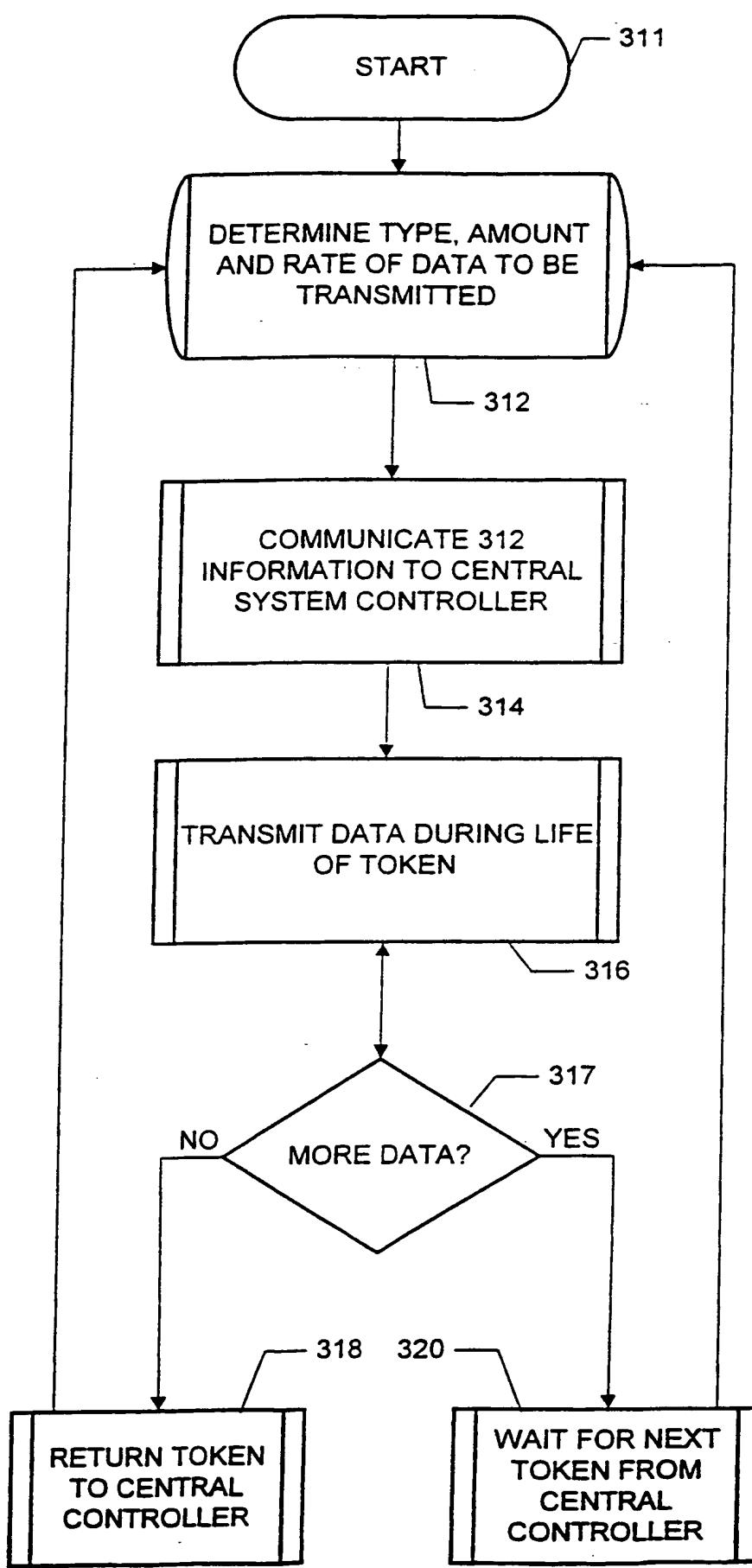
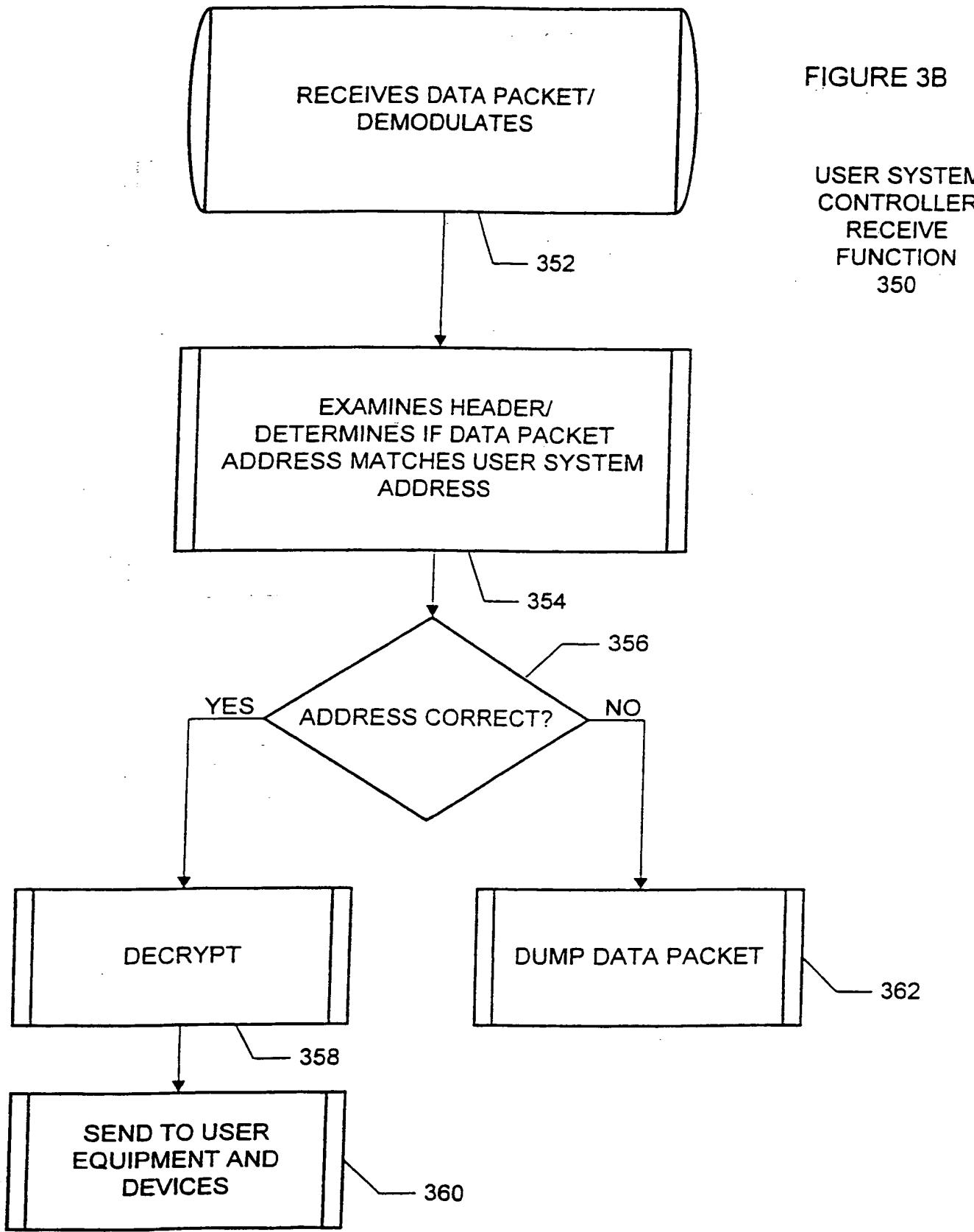


FIGURE 3A
USER SYSTEM
CONTROLLER
TRANSMIT
FUNCTION
WITH A TOKEN
RING TIME
DIVISION
MULTIPLEXING
(TDM) SYSTEM
300



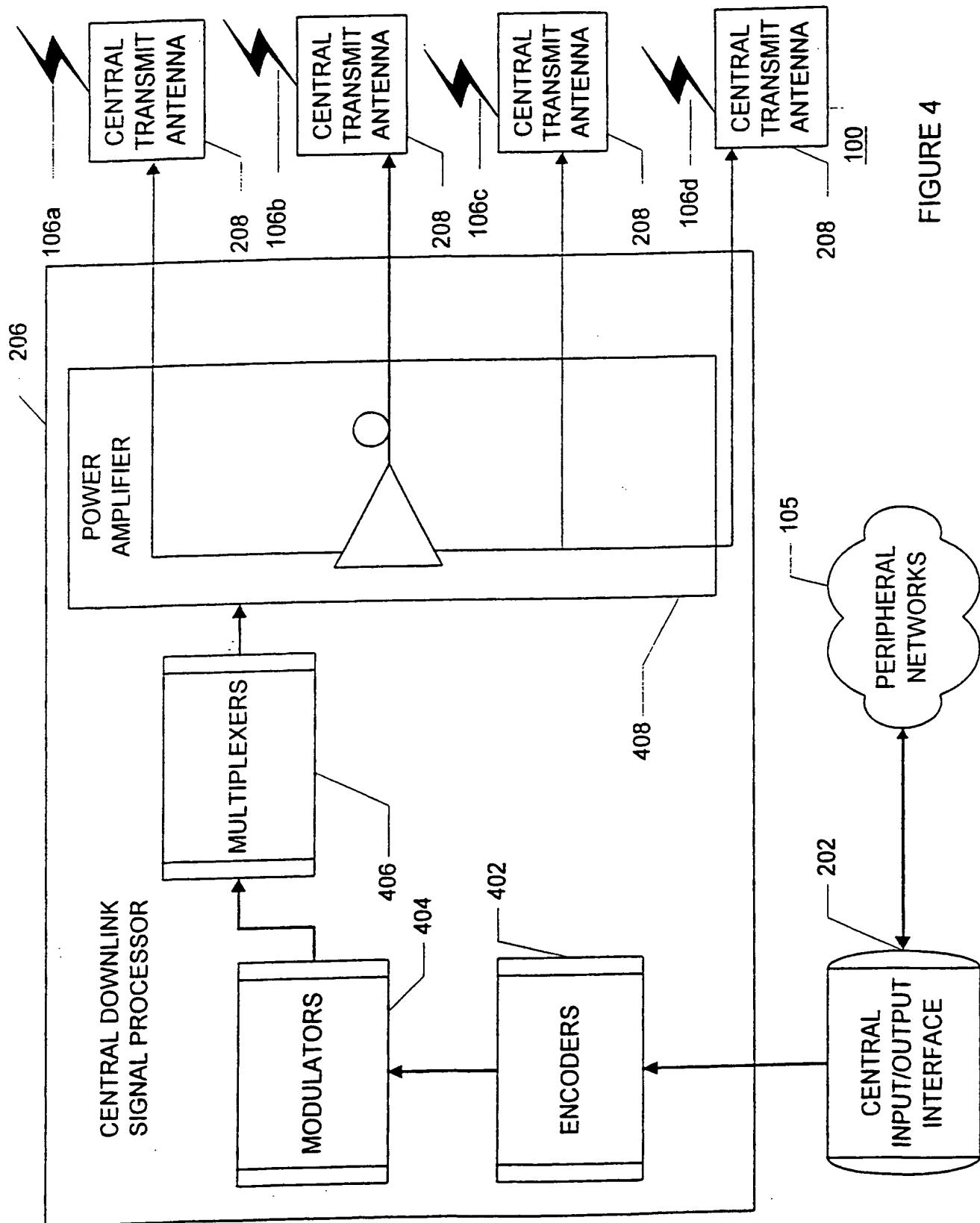
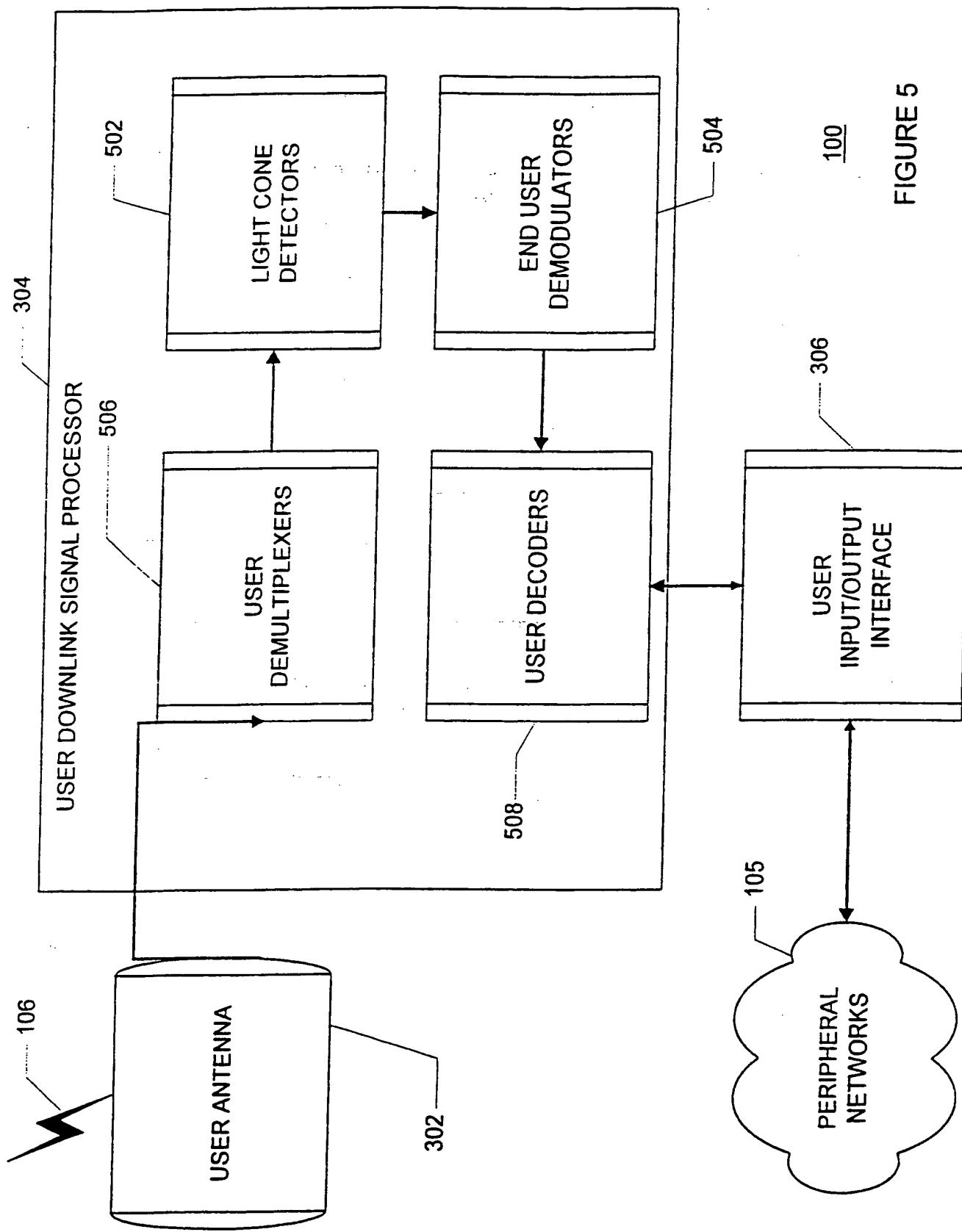


FIGURE 4



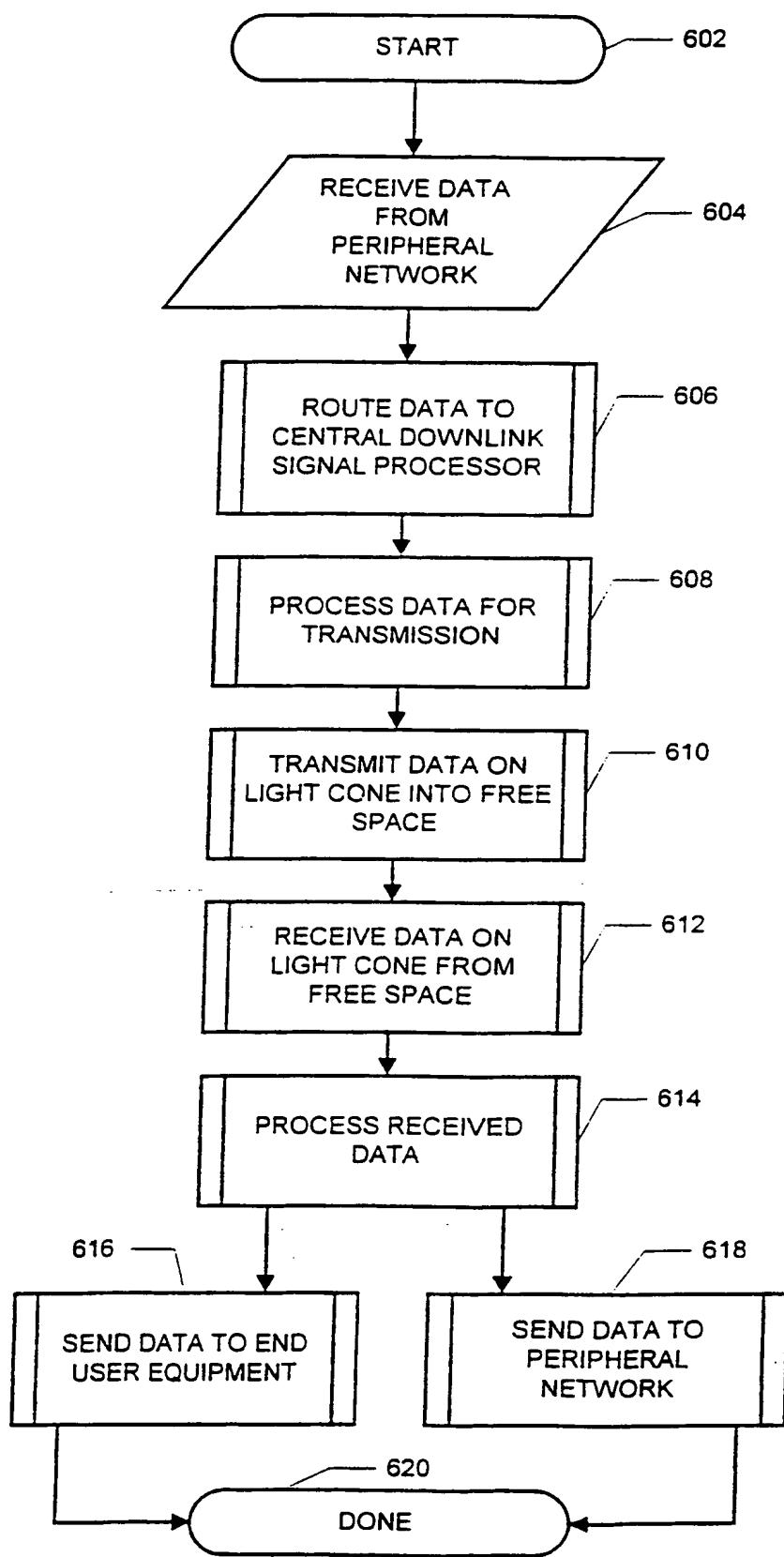
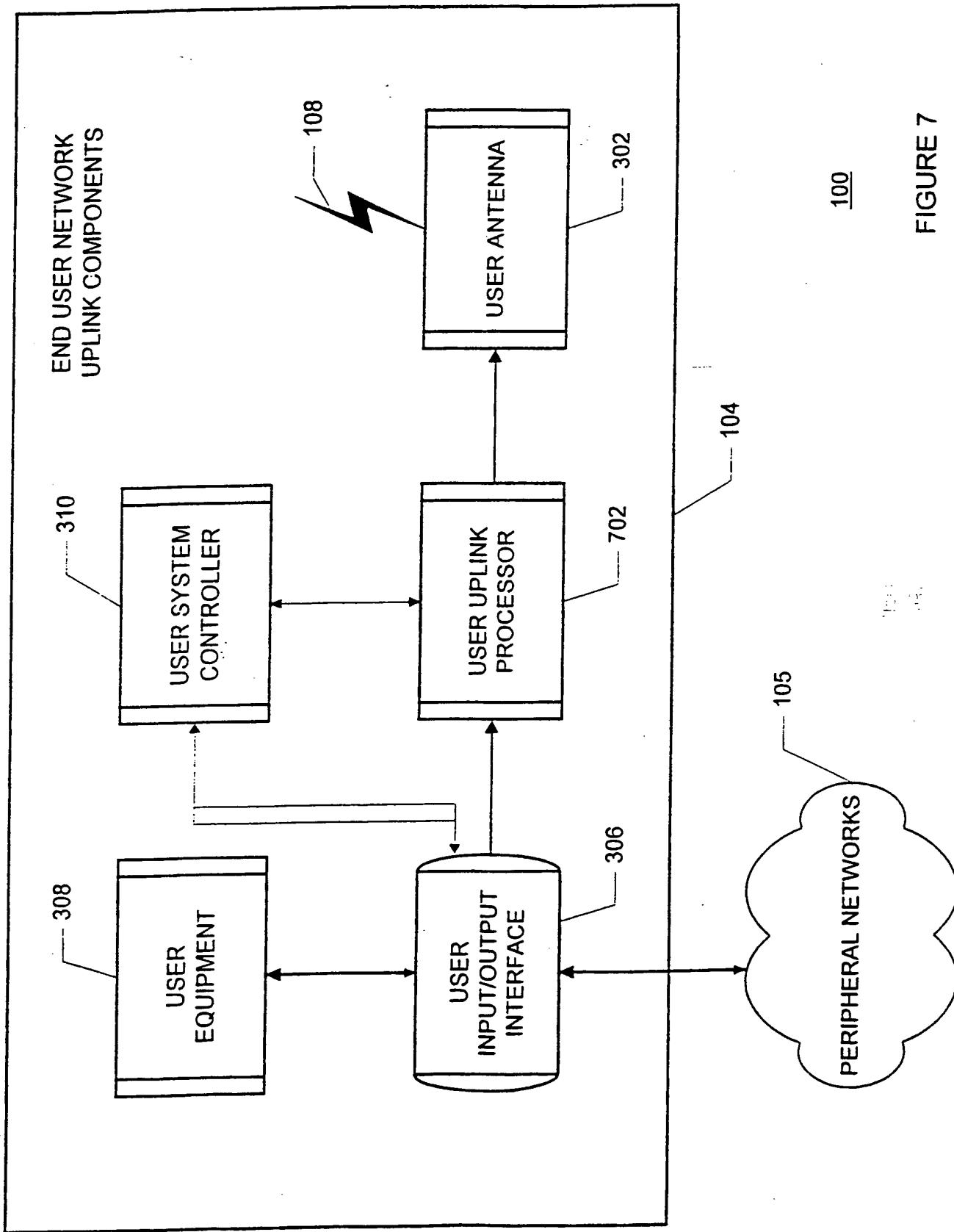


FIGURE 6

CENTRAL
NETWORK
RECEIVE
FUNCTION
600



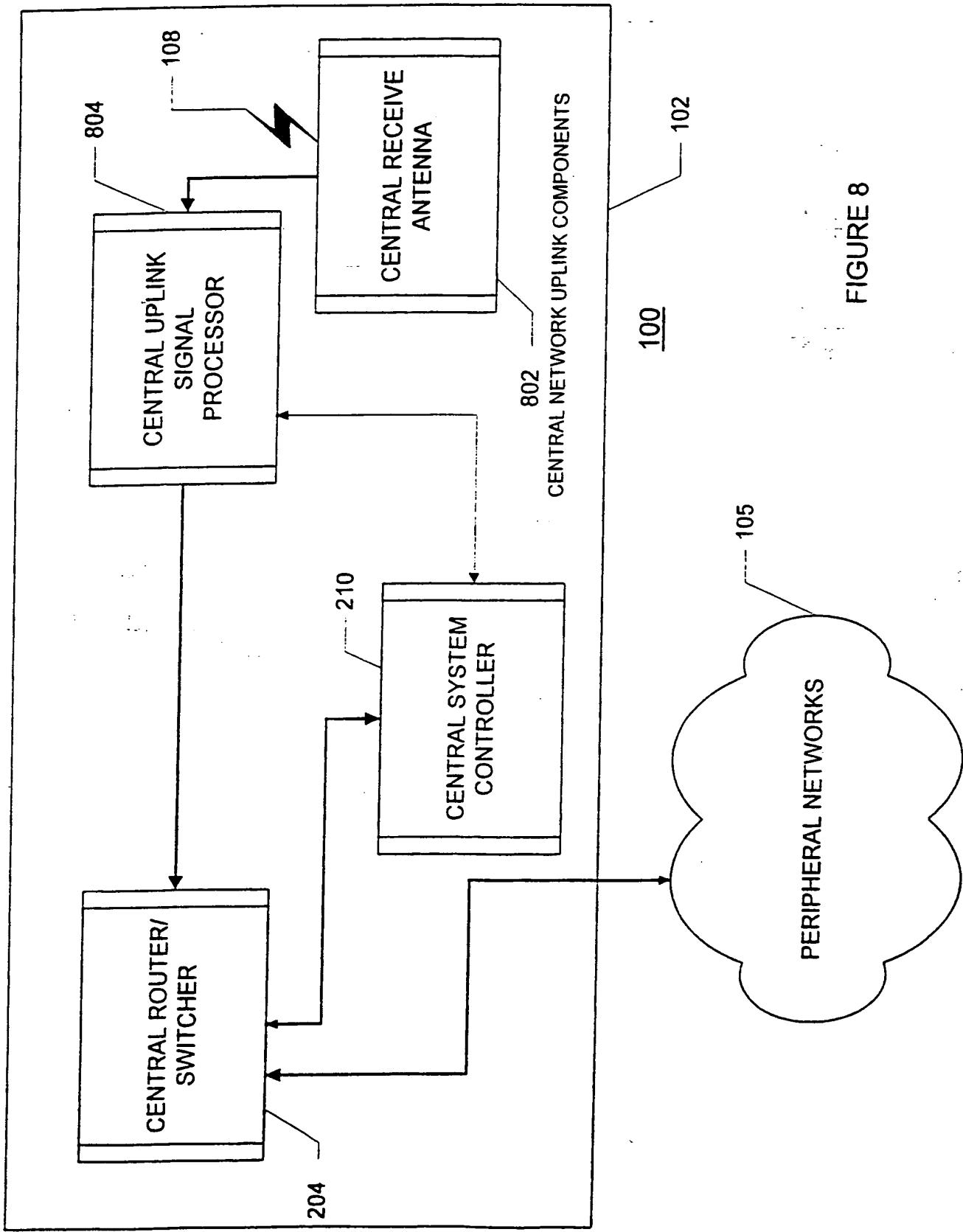


FIGURE 8

FIGURE 9

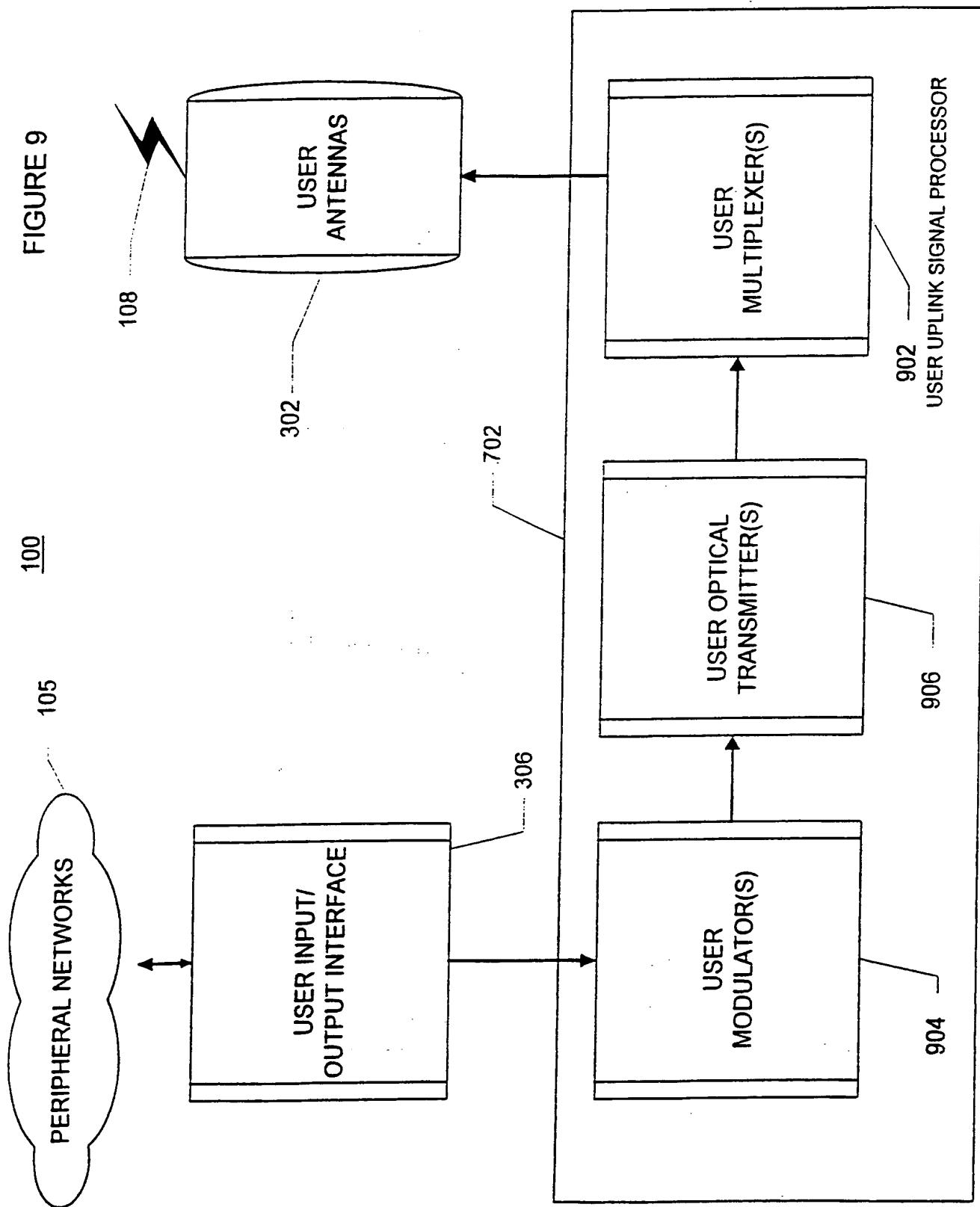
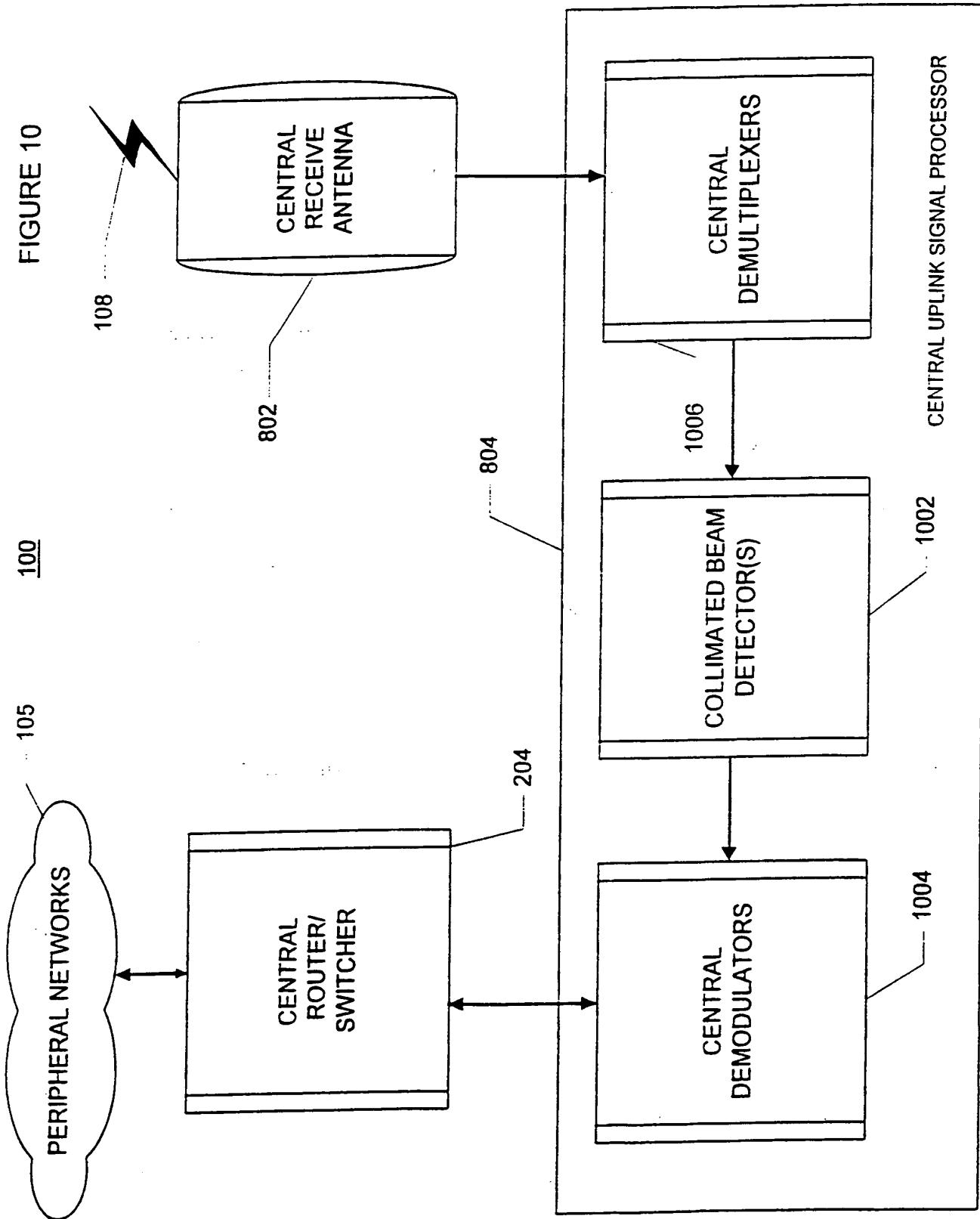
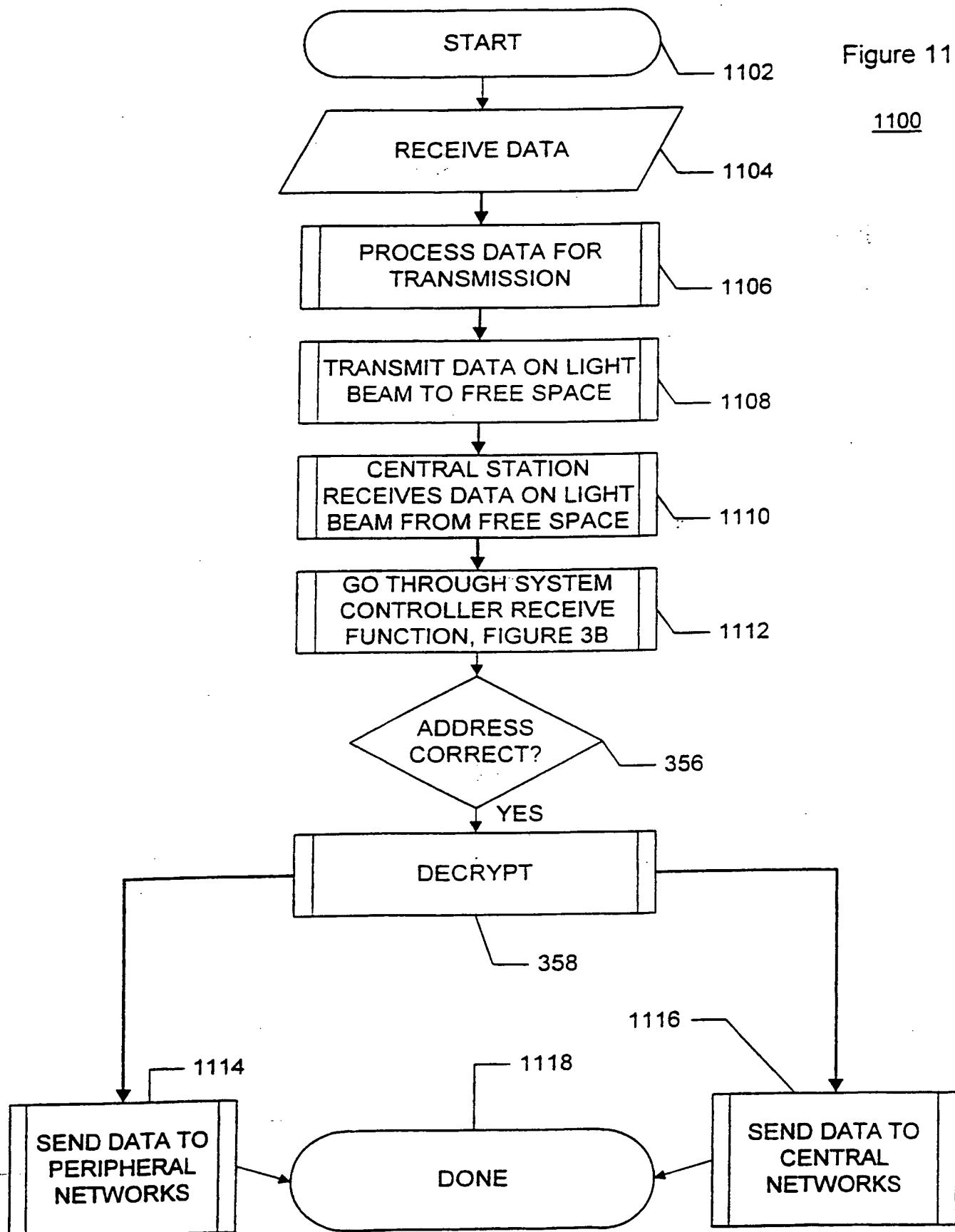


FIGURE 10





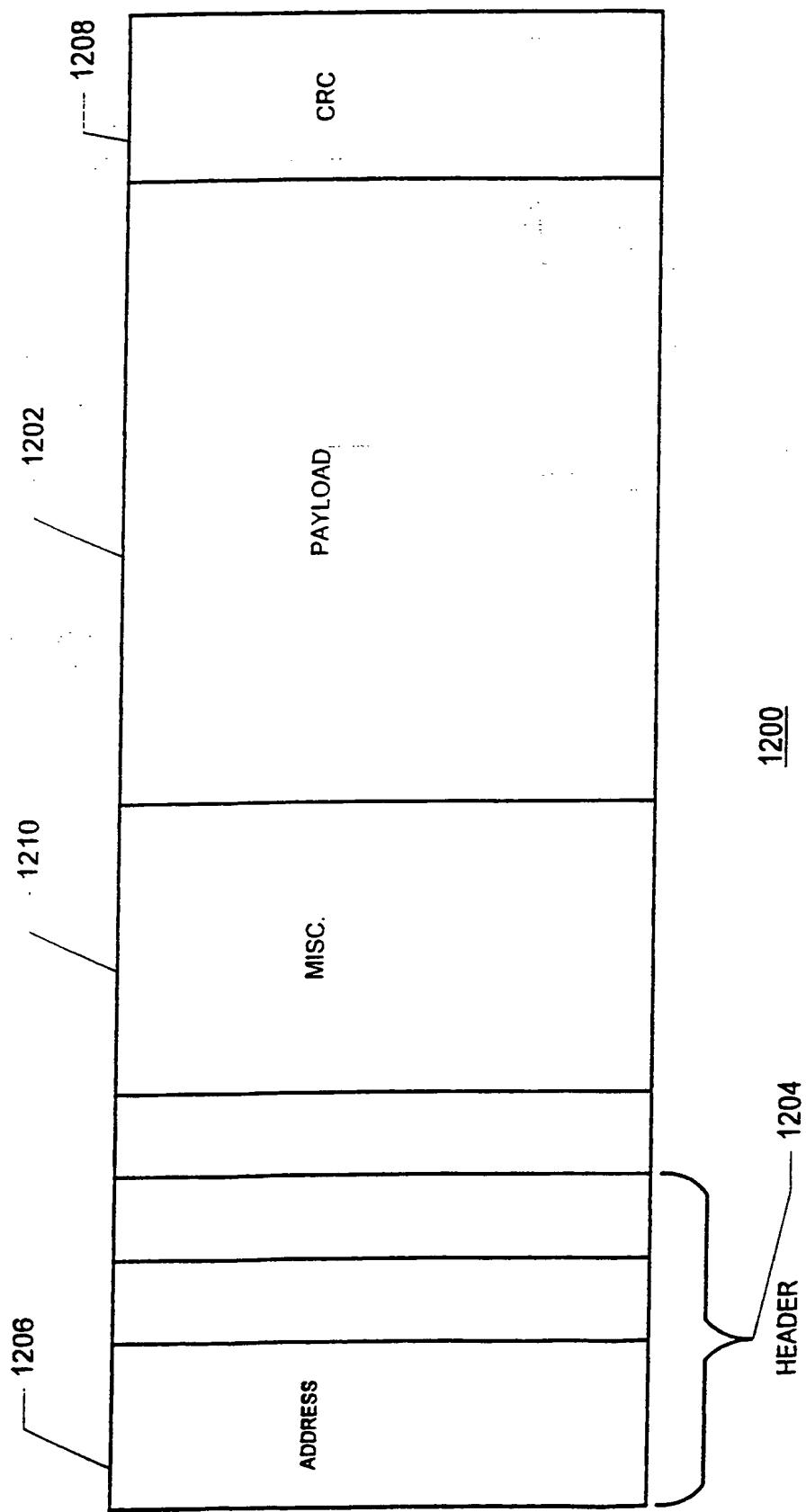


FIGURE 12

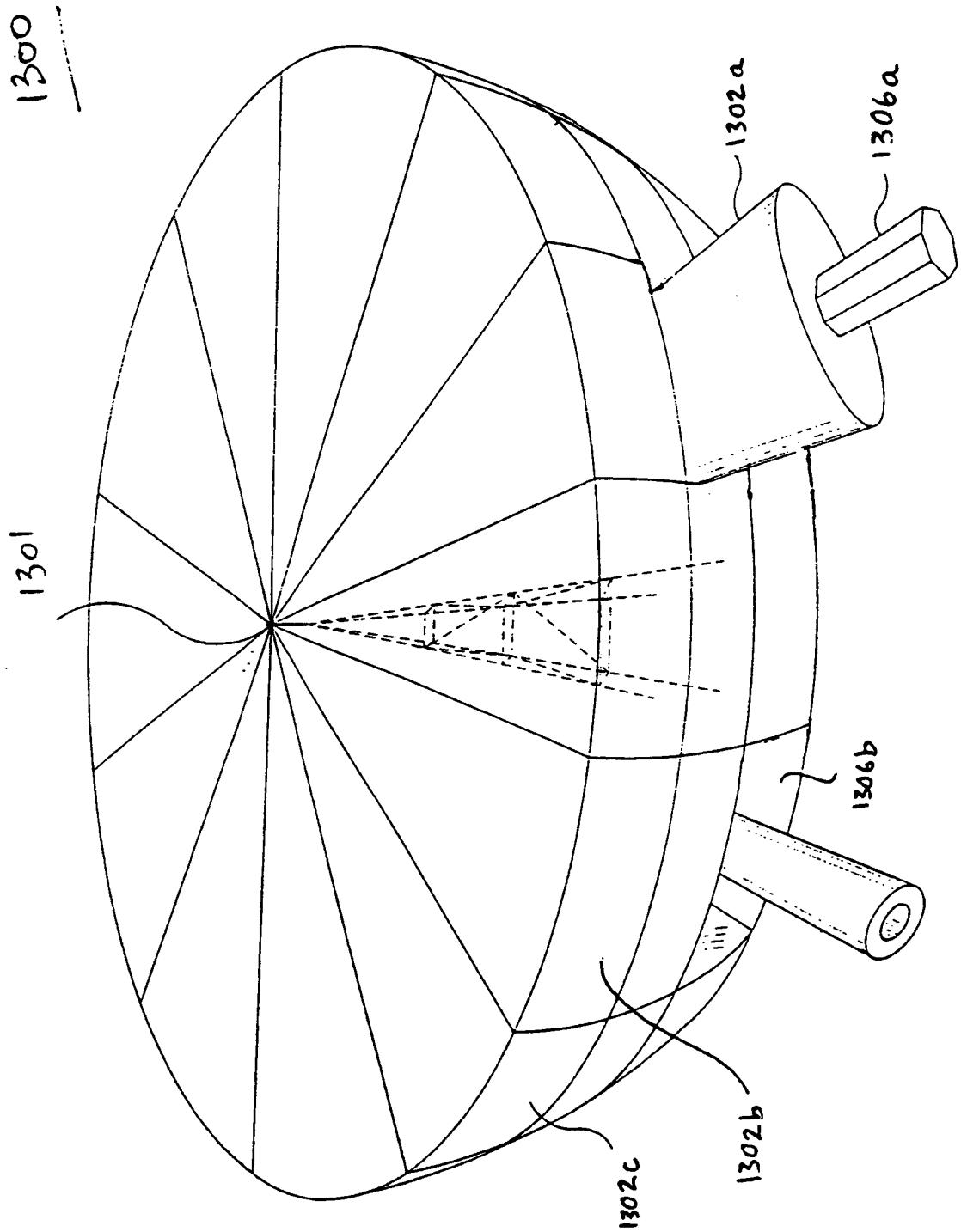


FIGURE 13

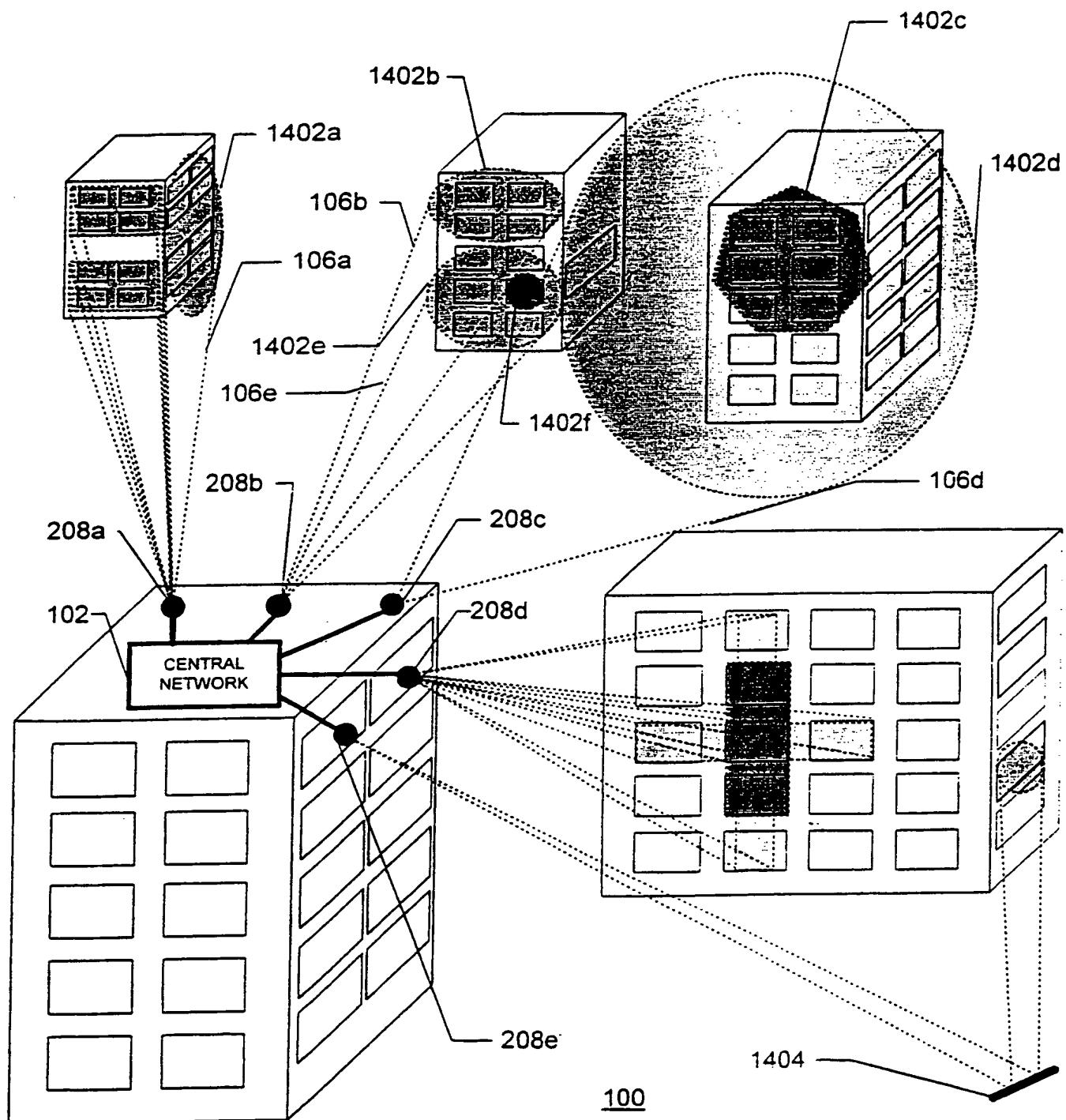


FIGURE 14

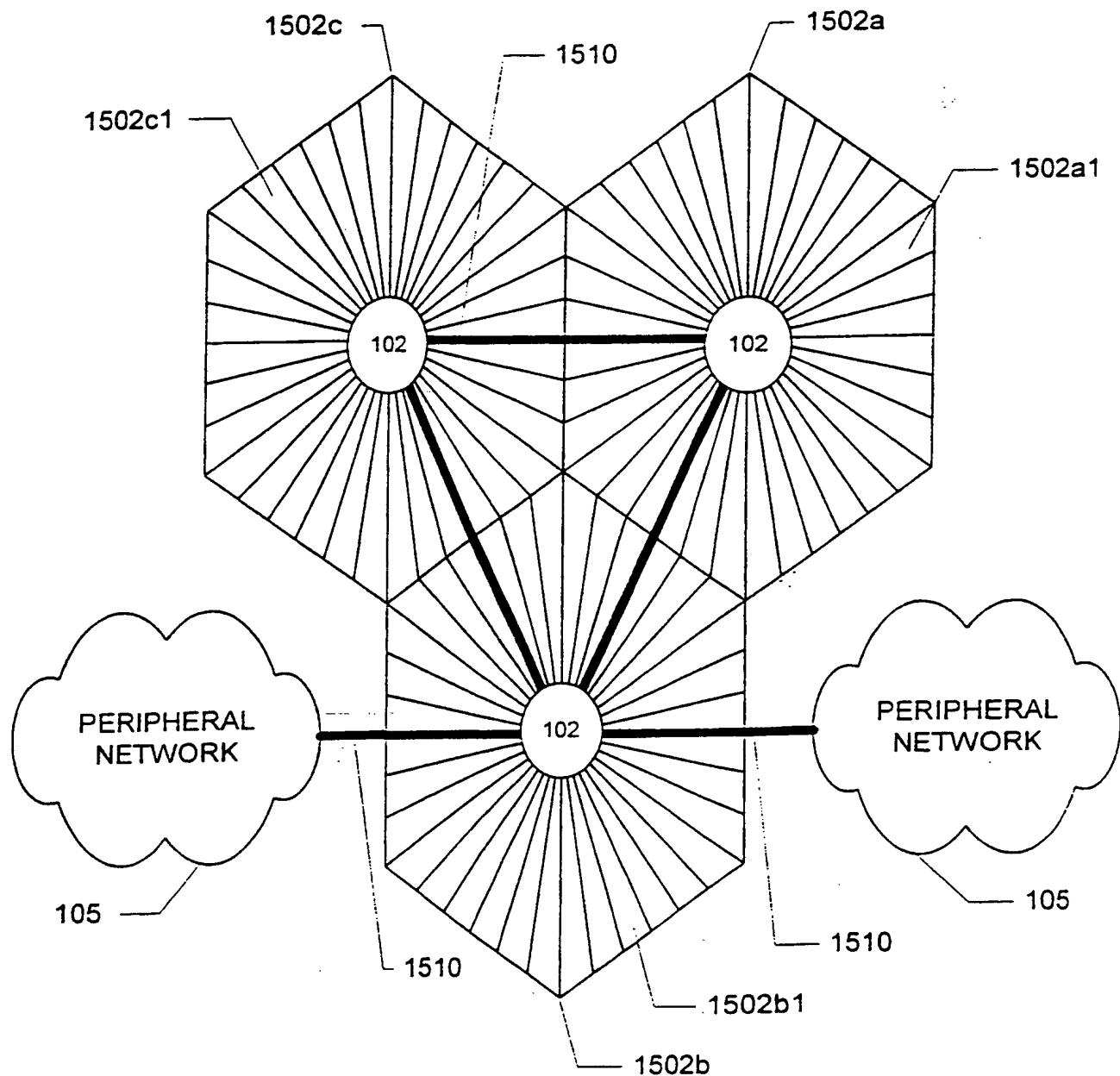
1500

FIGURE 15

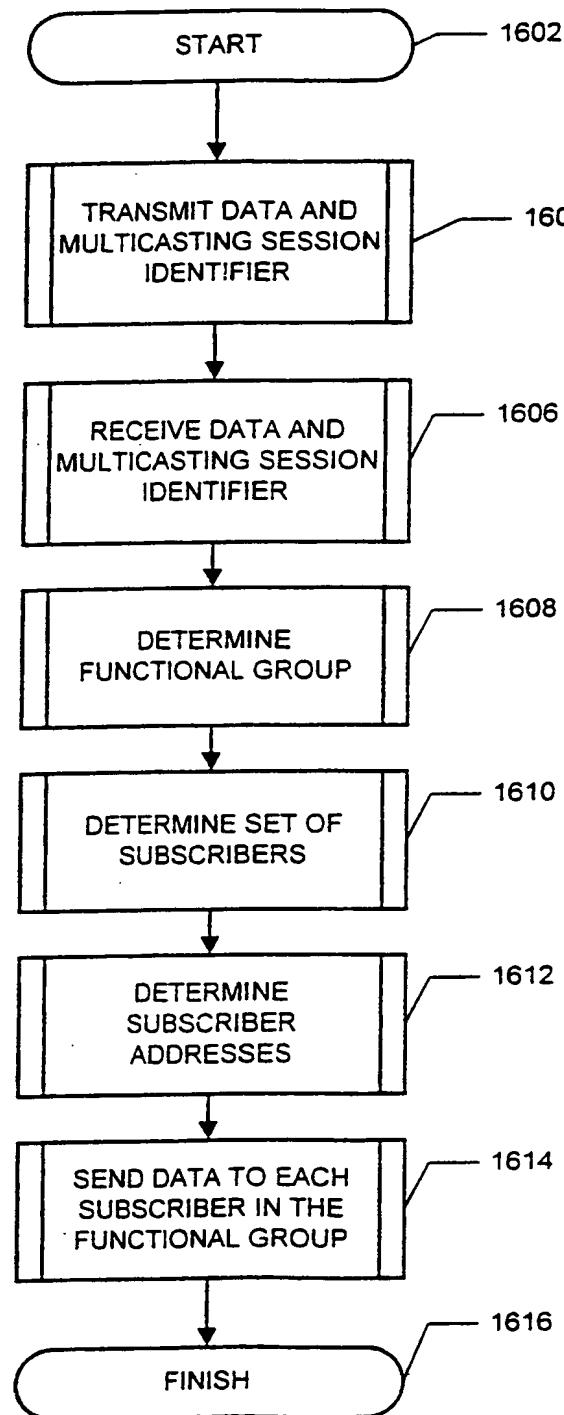


FIGURE 16

1600

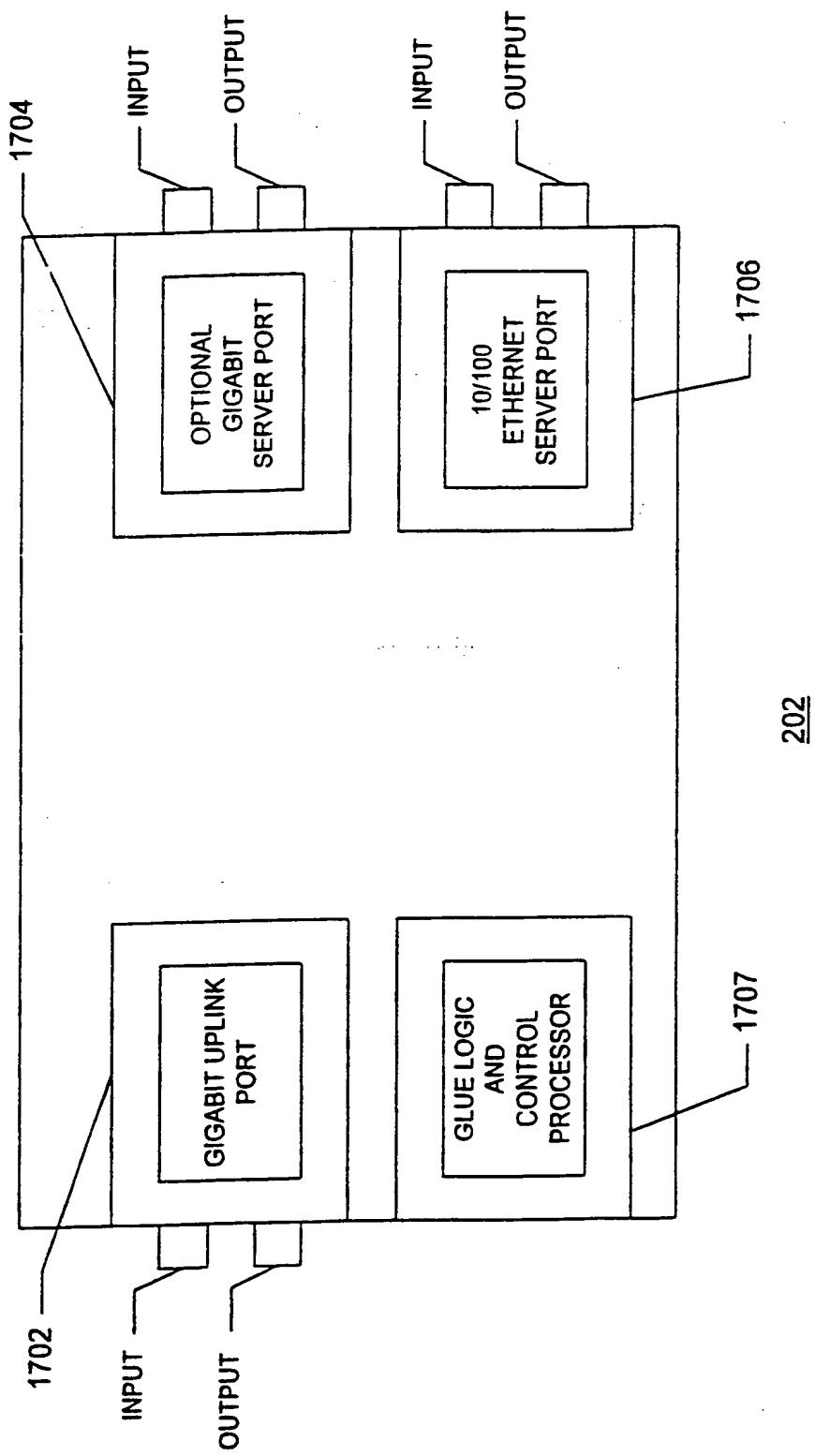


FIGURE 17

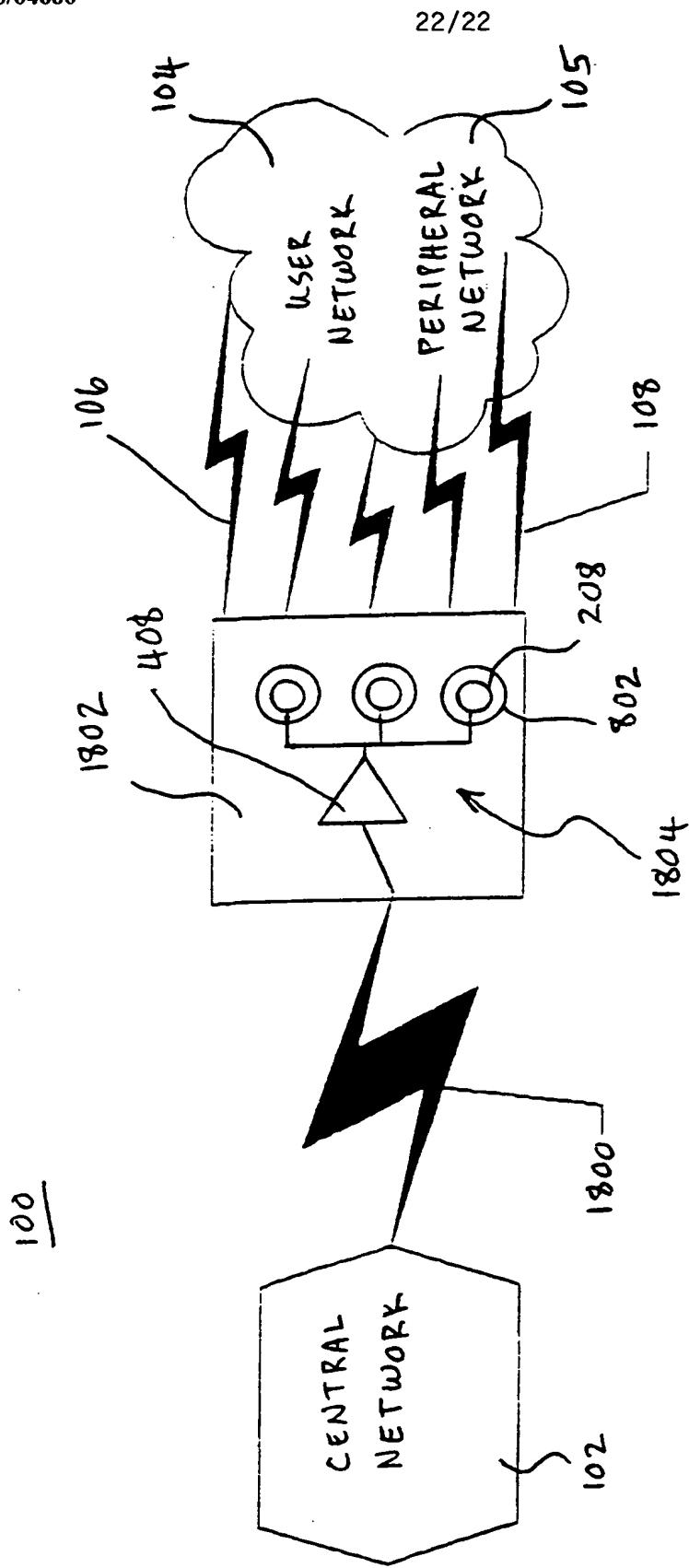


FIGURE 18

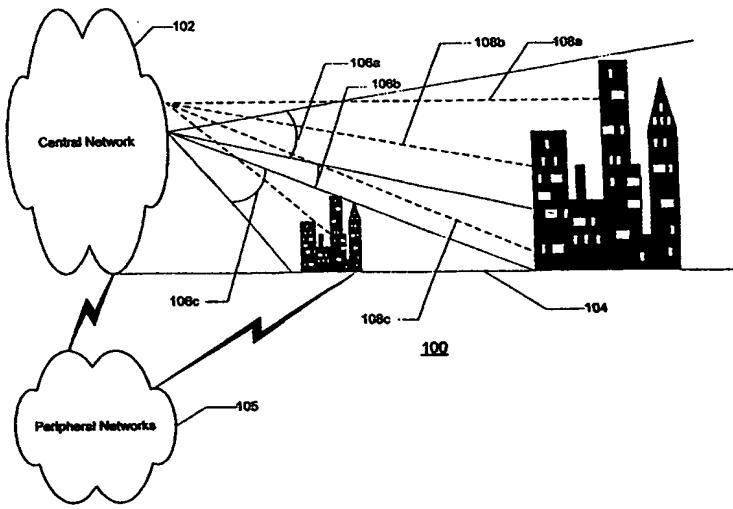
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| (51) International Patent Classification ⁷ : H04B 10/10 | | A3 | (11) International Publication Number: WO 00/04660 |
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| (30) Priority Data: 60/093,076 16 July 1998 (16.07.98) US Not furnished 7 July 1999 (07.07.99) US | | (74) Agents: DE GUZMAN, Dennis, M. et al.; Seed and Berry LLP, 6300 Columbia, 701 Fifth Avenue, Seattle, WA 98104-7092 (US). | |
| (71) Applicant (for all designated States except US): TERABEAM CORPORATION [US/US]; 1200 Mercer Street, Seattle, WA 98109 (US). | | (81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG). | |
| (72) Inventors; and | | Published With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments. | |
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(54) Title: OPTICAL COMMUNICATION SYSTEM THAT TRANSMITS AND RECEIVES DATA THROUGH FREE SPACE



(57) Abstract

A system and method for networked high-speed data communication through free space is described. The system includes one or more central networks, which contain one or more lasers modulated with high-speed data to illuminate with laser light areas surrounding the central network in which are located one or more user networks. The laser from the central network generates a radiation pattern that is sectored into horizontal and vertical sectors, and further divided into channels for each wavelength. Data coming from the user networks modulates a laser, which is transmitted as a collimated beam through free space back to the central network where it is received. Communication can be point-to-point, point-to-multipoint, multipoint-to-point, or multipoint-to-multipoint, and the point-to-multipoint communication can be broadcast, simulcast, or multicast.

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 99/15973A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04B10/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
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Electronic data base consulted during the International search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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|----------|---|--|
| X | WO 97 37445 A (DOMINION COMMUNICATIONS L L C) 9 October 1997 (1997-10-09) abstract; figures 1-10 | 1,26, 62-66, 68 2-18, 21-25, 27-33, 35-43, 45, 48-50, 55, 67, 69, 72, 75-84 34, 44, 46, 52, 59-61 |
| Y | | |
| A | page 2, line 6 -page 3, line 9 page 4, line 1 -page 5, line 12 page 5, line 29 - line 37 page 7, line 31 -page 8, line 16 page 9, line 1 -page 10, line 19 page 18, line 20 - line 21 -/- | |

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INTERNATIONAL SEARCH REPORT

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|----------|--|---|
| X | page 20, line 37 -page 21, line 11 page 21, line 38 - line 40 | |
| X | US 5 748 813 A (CASSIDY STEPHEN ANTHONY ET AL) 5 May 1998 (1998-05-05) | 70,71,74 |
| Y | column 1, line 47 - line 67; figures 1,6 | 30,31, 67,72, 75-84 |
| A | column 1, line 47 - line 64 | 19,20, 22,35 |
| Y | EP 0 653 852 A (CANON KK) 17 May 1995 (1995-05-17) | 2,10-18, 21-25, 27-29, 32,33, 35-43, 45, 48-50,55 |
| Y | column 5, line 40 -column 6, line 46 column 7, line 45 -column 8, line 13; figures 3-5 | |
| Y | MERCER L B: "ADAPTIVE COHERENT OPTICAL RECEIVER ARRAY" ELECTRONICS LETTERS, vol. 26, no. 18, 30 August 1990 (1990-08-30), pages 1518-1520, XP00010861 ISSN: 0013-5194 page 1518, right-hand column, last paragraph -page 1519, left-hand column, paragraph 2; figures 1,2 | 3 |
| Y | US 5 737 690 A (GUTMAN JOSE) 7 April 1998 (1998-04-07) | 4-9 |
| A | abstract; figures 1,3 | 1,3,26, 37,39,40 |
| Y | column 4, line 19 - line 60 column 12, line 34 -column 13, line 26 | |
| Y | PATENT ABSTRACTS OF JAPAN vol. 017, no. 563 (P-1628), 12 October 1993 (1993-10-12) & JP 05 164532 A (MITSUBISHI ELECTRIC CORP), 29 June 1993 (1993-06-29) abstract | 69 |
| A | EP 0 631 401 A (CANON KK) 28 December 1994 (1994-12-28) claims 1-3; figures 1,2,6,8 | 62-66, 70-78 |
| A | WO 98 18220 A (MOTOROLA INC) 30 April 1998 (1998-04-30) | 62-66, 70-72, 75-78 |
| | claims 1-4; figures 1-6 | |

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 99/15973

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. Claims Nos.: because they relate to subject matter not required to be searched by this Authority, namely:

2. Claims Nos.: because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. Claims Nos.: because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

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This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

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INTERNATIONAL SEARCH REPORT

International Application No. PCT/US 99/15973

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. Claims: 1-3,26-31,37-40

Communication system and method for transmitting and receiving data between peripheral points and user points via a central point using free space modulated light beams.

2. Claims: 4-9

Central point to user communication method using modulation of data and user address on a light beam.

3. Claims: 10-25,32-36,41-61

Free space light transmission system, apparatus and method using information modulation on a diverging coherent light beam.

4. Claims: 62-75

Data transmission system and method transmitting information along several sectors.

5. Claims: 76-84

Communication system with a central node splitting an input signal into plural substantially similar output signals and transmitting them optically to a user node as well as receiving a plurality of optical signals.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 99/15973

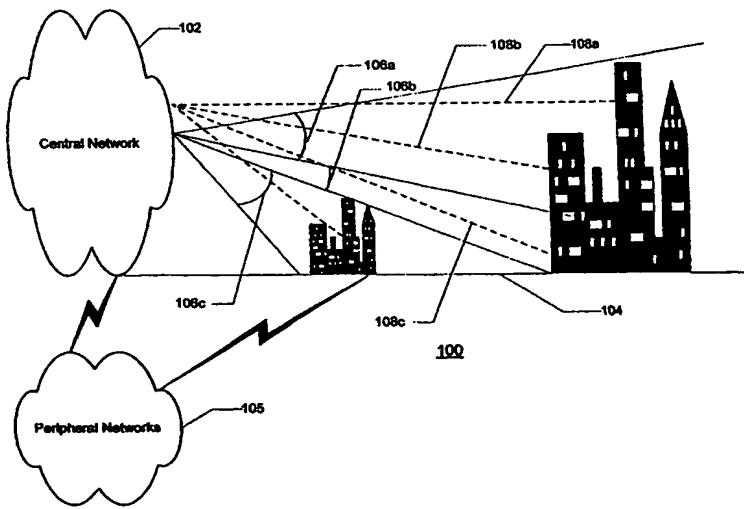
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| | | | (43) International Publication Date: 27 January 2000 (27.01.00) |
| (21) International Application Number: PCT/US99/15973 | | | Issaquah, WA 98129 (US). WYER, Jorah [US/US]; Apt. 63, 301 E. Roy, Seattle, WA 98102 (US). WEBB, James [US/US]; #9, 15 W. Etrui Street, Seattle, WA 98119 (US). |
| (22) International Filing Date: 15 July 1999 (15.07.99) | | | |
| (30) Priority Data: 60/093,076 16 July 1998 (16.07.98) US 09/348,440 7 July 1999 (07.07.99) US | | | (74) Agents: DE GUZMAN, Dennis, M. et al.; Seed and Berry LLP, 6300 Columbia, 701 Fifth Avenue, Seattle, WA 98104-7092 (US). |
| (71) Applicant (for all designated States except US): TERABEAM CORPORATION [US/US]; 1200 Mercer Street, Seattle, WA 98109 (US). | | | (81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG). |
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| (75) Inventors/Applicants (for US only): AMADON, Charles, Gregory [US/US]; 1017 East Blaine Street, Seattle, WA 98102 (US). CRONIN, Alexander, Douglas [US/US]; Apt. B-124-3, 3801 Brooklyn Avenue N.E., Seattle, WA 98015 (US). ELLIOTT, Cameron, S. [US/US]; Apt. 186, 323 Broadway E., Seattle, WA 98102 (US). RALLISON, Richard, D. [US/US]; Box 142, 8501 South 400 West, Paradise, UT 84328 (US). STEVENS, James, Charles [US/US]; 9707 35th Avenue N.E., Seattle, WA 98115 (US). ZIKAN, Karel [US/US]; 4640 Sunnyside Avenue N., Seattle, WA 98103 (US). SCHUSTER, John [US/US]; #15, 2680 139th Avenue S.E., Bellevue, WA 98005 (US). PRATT, Mark [US/US]; G104, 25025 S.E. Klahanie, | | | (88) Date of publication of the international search report: 4 May 2000 (04.05.00) |

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(57) Abstract

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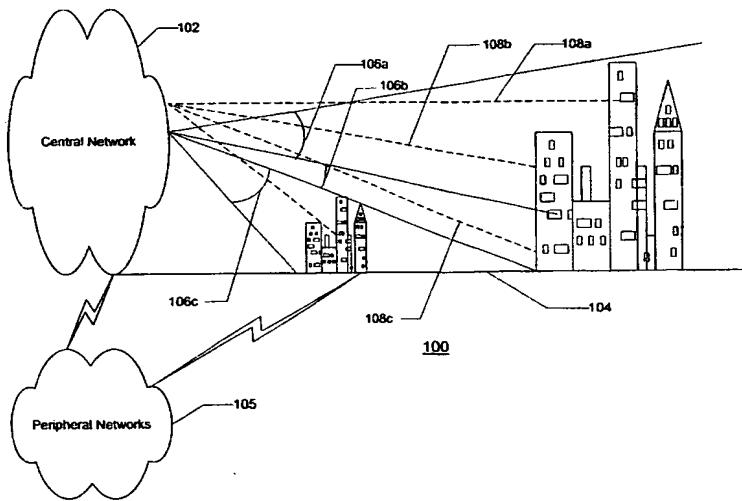
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(54) Title: OPTICAL COMMUNICATION SYSTEM THAT TRANSMITS AND RECEIVES DATA THROUGH FREE SPACE



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(57) Abstract: A system and method for networked high-speed data communication through free space is described. The system includes one or more central networks, which contain one or more lasers modulated with high-speed data to illuminate with laser light areas surrounding the central network in which are located one or more user networks. The laser from the central network generates a radiation pattern that is sectored into horizontal and vertical sectors, and further divided into channels for each wavelength. Data coming from the user networks modulates a laser, which is transmitted as a collimated beam through free space back to the central network where it is received. Communication can be point-to-point, point-to-multipoint, multipoint-to-point, or multipoint-to-multipoint, and the point-to-multipoint communication can be broadcast, simulcast, or multicast.



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OPTICAL COMMUNICATION SYSTEM THAT TRANSMITS AND RECEIVES DATA THROUGH FREE SPACE

TECHNICAL FIELD

The present invention is related generally to data communication systems and, in particular, to free space optical data communication networks.

BACKGROUND OF THE INVENTION

Existing telecommunication systems may be useful for providing traditional telecommunication services, but generally are confined to relatively low-speed, low-capacity applications. For example, standard telephone lines are limited to data rates of approximately 60 kilobits per second (Kbps) per telephone line, well-known Integrated Services Digital network (ISDN) services provide data rates up to 128 Kbps, and Asymmetrical Digital Subscriber Line (ADSL) services are limited to eight megabits per second (Mbps) data rates. Similarly, conventional satellite networks can deliver data to end users at up to 15 30 Mbps per satellite, and Local Multipoint Distribution Services (LMDS) appear to have an upper limit of about four to eight gigabits per second (Gbps) per two km cell. These data rates, especially when divided between multiple users, soon prove to be insufficient for many modern applications, such as video teleconferencing and multimedia applications.

Because a typical personal computer can transmit and receive data via Ethernet at data rates in excess of 100 Mbps, individuals and businesses alike may find attractive telecommunication services that accommodate those data rates. For example, many customers may desire high-speed data communication for use with the Internet and the World Wide Web, high resolution video teleconferences, video telephony, large multi-gigabyte file transfers, etc. This means that for telecommunication service providers to thrive in today's globally competitive environment, any future telecommunication system must meet these demands without unreasonable costs.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1A is a block diagram of a communication system suitable for implementing an embodiment.

5 Figure 1B is an isometric view showing a side of the communication system of Figure 1A.

Figure 2 is a block diagram of an illustrative central network components for downlink transmission using the communication system in Figure 1B.

10 Figure 2A is a flow diagram of an illustrative central system controller transmit function.

Figure 3 is a block diagram of illustrative user network downlink reception components.

Figure 3A is a flow diagram of an illustrative user system controller transmit function.

15 Figure 3B is a flow diagram of an illustrative user system controller receive function.

Figure 4 is a block diagram of illustrative central downlink signal processor components.

20 Figure 5 is a block diagram of illustrative user downlink signal processor components.

Figure 6 is a flow diagram of an illustrative downlink data transmission and reception process.

Figure 7 is a block diagram of illustrative user network uplink transmission components.

25 Figure 8 is a block diagram of illustrative central network uplink reception components.

Figure 9 is a block diagram of illustrative user uplink signal processor components.

30 Figure 10 is a block diagram of illustrative central network uplink components.

Figure 11 is a flow diagram of an uplink data transmission and reception process.

Figure 12 illustrates a data packet suitable for use with the communication system of Figure 1A.

5 Figure 13 illustrates an illustrative transmission point with sectorization.

Figure 14 illustrates examples of various suitable radiation patterns generated by the central transmit antennas in the illustrative central network components of Figure 2.

10 Figure 15 illustrates an illustrative topography produced by the sectorization of Figure 13.

Figure 16 is a flowchart illustrating an illustrative multicast process.

Figure 17 shows an illustrative central input/output interface.

15 Figure 18 is a block diagram showing an alternative embodiment of the communication system of Figures 1A and 1B.

In the figures, like reference numbers refer to similar elements. In addition, the most significant digit in a reference number refers to a figure in which that element is first introduced (e.g., an element 204 is first introduced in 20 Figure 2).

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

A communication system, and in particular, a system and method for optical communications in free space is described herein. In the following description, numerous specific details, such as specific symbols and relationships, specific methods of and structures for transmitting, receiving, and processing high speed data, etc., are set forth to provide a full understanding of embodiments of the invention. One skilled in the relevant art, however, will readily recognize that the invention can be practiced without one or more of the specific details, or with other methods and structures, etc. In other instances,

well-known structures or operations are not shown in detail to avoid obscuring the description of the embodiments.

Embodiments of the invention are directed to systems, methods, and interconnected devices for networked, high-speed, bi-directional data communication through free space having one or more centrally located transmit/receive stations which use one or more lasers modulated with encrypted, high-speed (10 Mbps-10 Gbps) data and control signals to illuminate with laser light some or all of the areas surrounding the centrally located transmit/receive stations. The illuminated areas surrounding the centrally located transmit/receive stations encompass one or more user optical receivers having light gathering and filtering elements, active tracking devices, optical detectors, and demultiplexing and decoding circuitry, which receive and select portions of the centrally located transmit/receive stations laser high-speed data stream for output to a user optical transceiver interface output, which is in turn may be connected via a high-speed networking connection to user equipment.

Data coming from user equipment on a 100 Mbps megabit Ethernet goes to the user optical transceiver interface input and modulates a laser collocated in the user optical transceiver. The user optical transceiver sends a collimated laser beam through free space back to the centrally located transmit/receive stations, where the collimated laser beam is received by light gathering and filtering elements, and active and actively tracking matrix detectors, where the data is detected and directed into data routing circuits. The data routing circuits route the data to node addresses, which can be either within one centrally located transmit/receive station area or within other centrally located transmit/receive station areas, via a high-speed free space optical backbone network-to-network links or anywhere on other networks connected to the centrally located transmit/receive stations(s) routing circuitry.

The centrally located transmit/receive stations routing circuitry also routes incoming data addressed to any or all user optical transceiver(s) by encoding that data into the high-speed data stream of the particular centrally

located transmit/receive station laser being detected by the respective user optical transceiver. The laser beams illuminate the area surrounding the centrally located transmit/receive stations in a variety of radiation patterns. The radiation patterns are sectored horizontally (or radially) and/or vertically (or by elevation).

5 The sectors may be further subdivided into several wavelength channels. The networks transmit and receive data using the channels.

Of course, those skilled in the art will appreciate that the invention is not limited to this embodiment. Instead, the invention supports a variety of embodiments, some of which are described more fully below.

10 The Communication System

Figure 1A is a block diagram of a communication system 100 suitable for implementing an embodiment. The communication system 100 can be thought of as a hierarchic system with a set of interconnected networks, where each network is a node in the communication system 100, and where each network is interconnected. For example, the communication system 100 can include as nodes one or more central networks 102, user networks 104, and/or peripheral networks 105.

20 Data is exchanged among the networks. In one embodiment of the invention, data is sent from the central networks 102 to the user networks 104 using shaped and diverging coherent light beams (or light cones) 106, and data is sent from the user networks 104 to the central networks 102 using collimated light beams 108. Each individual network also can include a hierarchy of interrelated subsystems with lower level nodes (or network elements), which is described more fully below. Data is exchanged among the networks point-to-point, point-to-multipoint, multipoint-to-point, or multipoint-to-multipoint, and point-to-multipoint communication can be broadcast, multicast, or simulcast.

25 For example, during point-to-point communication, any one of the central networks 102 or their lower level nodes can transmit data from itself to any one node in the user networks 104 or the peripheral networks 105. Likewise,

any of the central networks **102** or their lower level nodes can receive data from any one of the user networks **104** or their lower level nodes, as well as from any one of the peripheral networks **105** or their lower level nodes.

During point-to-multipoint communication, any one of the central networks **102** or their lower level nodes can transmit data from itself to several user networks **104** or their lower level nodes substantially simultaneously. Any one of the central networks **102** or their lower level nodes can transmit data from itself to several peripheral networks **105** or their lower level nodes substantially simultaneously. Likewise, any of the central networks **102** or their lower level nodes can receive data from any of the user networks **104** or their lower level nodes substantially simultaneously, as well as from any of the peripheral networks **105** or their lower level nodes substantially simultaneously.

The hierarchy of the communication system **100** can feature networks interconnected with each other, as Figure 1A illustrates. The embodiment does not require that the peripheral networks **105** and the user networks **104** be interconnected, or that the central networks **102** be connected to both the peripheral networks **105** and the user networks **104**. Moreover, the central networks **102** may be interconnected to each other such that data is transmitted among the individual central networks **102** without passing through a peripheral network **105** or a user network **104**. This particular embodiment reduces the costs of operation, for example, by allowing central networks to carry their own backbone traffic, unlike other wireless networks that dedicate all of their bandwidth to the user networks.

In one embodiment of the invention, a user network **104** is operated by a user that subscribes with the peripheral networks **105** and/or the central networks **102** to send and receive data in a client-server environment. The users may be located at a manufacturing facility, a multinational corporation, a financial institution, or a university, for example, with buildings that house the network components. In that instance, the central networks **102**, the user networks **104**, and the peripheral networks **105** connect "client" systems with

“server” systems so that the server systems may perform a computation, retrieve a file, or search a database for a particular entry in response to a request by the client system. A particular type of client-server environment is not essential to the embodiment. It will be apparent to those skilled in the art that the 5 embodiments may be implemented in other client-server environments, such as airline flight reservations systems, mail-order facilities, etc.

The peripheral networks **105** can be any interconnected network operated by a common carrier, including a Public Switched Telephone Network (PSTN), a Local Exchange Carrier (LEC) network providing local 10 telecommunication services, an Interexchange Carrier (IXC) providing long distance telecommunication services, a satellite network, a value added network (e.g., providing dial-up stock market quoting services, electronic mail services, etc.). Alternatively, the peripheral networks **105** can be a collection of networks functioning as a virtual network, including the Internet, the World Wide Web, 15 etc. The peripheral networks **105** also can include data communication networks such as Local Area Networks (LANs), Metropolitan Area Networks (MANs), or Wide Area Networks (WANs). Of course, those skilled in the art will appreciate that a particular type of peripheral network **105** is not required by the embodiment. Instead, any type of peripheral network **105** may be used.

20 In one embodiment, the central networks **102**, the user networks **104**, and the peripheral networks **105** utilize Synchronous Optical Network (SONET) technology, which is an optical interface standard that allows internetworking of transmission products from multiple vendors. That is, when the communication system **100** implements SONET technology, interconnection 25 of the networks enables worldwide data communication. Moreover, when the communication system **100** implements SONET technology, a new digital hierarchy ideally suited to handling fiber-based signals and at the same time allowing easy extraction of lower rate signals is accomplished. These include unified operations and maintenance and the flexibility to allow for future service 30 offerings.

In an alternative embodiment, the central networks 102, the user networks 104, and the peripheral networks 105 utilize Gigabit Ethernet technology, which is an optical interface standard that allows internetworking of transmission products from multiple vendors. That is, when the communication system 100 implements Gigabit Ethernet technology, interconnection of the networks enables worldwide data communication, especially real-time voice and video and high-end server support. Moreover, when the communication system 100 implements Gigabit Ethernet technology, a new digital hierarchy ideally suited to handling fiber-based signals and at the same time allowing easy extraction of lower rate signals is accomplished. These include unified operations and maintenance and the flexibility to allow for future service offerings.

Figure 1B is an isometric view showing a side of the communication system 100, where data is exchanged between the central networks 102 and the user networks 104 in free space using the light cones 106a-c and the collimated light beams 108a-c. In one embodiment, the light cones 106a-c are shaped and diverging coherent light beams, such as light amplification of stimulated emission of radiation, or "laser" beams. Laser beams are directional, and can operate in a range of wavelengths in the "light" region of the electromagnetic spectrum, including visible light, near-infrared light, and infrared light. When the light cones 106a-c are laser beams, the light cones 106a-c accommodate high bit rate, high power, high coupling efficiency, direct high frequency modulation, and long haul operations. In one embodiment, the light cones 106a-c are eye-safe, class one laser beams, in accordance with American National Standards Institute (ANSI) standards. In alternative embodiments, the light cones 106a-c operate in accordance with other ANSI standards.

The use of particular wavelengths of laser light provides high bandwidth with very little attenuation (or power loss) in the atmosphere. Moreover, using laser light allows interconnection with SONET architectures

operating at high speeds between central networks 102 typical of off-the-shelf data transmission equipment currently available. Moreover, in this embodiment, using the SONET protocol allows arbitrary bandwidth allocation in the well-known portions of T-1 capacity. That is, when the communication system 100 5 uses the laser lights with SONET, it can accommodate a digital transmission link with the capacity of 1.544 Mbps to many different users across remote distances.

One embodiment of the communication system 100 uses an infrared laser with a wavelength of approximately 1550nm. Of course, those skilled in the art will appreciate that a particular wavelength in the light region of 10 the electromagnetic spectrum is not required by the embodiment. Instead, any wavelength in the light region may be used.

The light cones 106a-c and the collimated light beams 108a-c can be generated using any well-known holographic optical elements that shape, filter, and diverge or collimate the light appropriately. For example, beam 15 shaping can be accomplished using diffraction gratings, lenses, holographic optical elements, or other standard beam-shaping optic. Wavelength filtering, used in various channelization schemes, can also be achieved using a variety of standard optical components such as interference filters, diffraction gratings, or prisms.

As is described more fully below, the light cones 106a-c bit rate in 20 one embodiment may be between 10 Mbps and 10 Gbps, inclusive. Of course, those skilled in the relevant art will appreciate that a particular data rate is not required for the embodiment. That is, the embodiments of the invention support any number of data rates.

As is the case with the light cones 106a-c, the collimated light 25 beams 108a-c also can be laser beams or any light beam at a wavelength in the "light" region of the electromagnetic spectrum, including visible light, near-infrared light, and infrared light. Collimating can be accomplished in a well-known manner, such as by using a diffraction gratings, lenses, or other standard 30 beam-shaping optics.

Of course, those skilled in the art will appreciate that, while much of the communications within the communication system **100** involves the wireless exchange of extremely high-speed, broadcast, digital data, the communication network **100** also supports conventional methods of data communication, such as telephone lines. For example, a central network **102** can transmit Internet video data at an extremely high speed to a user network **104** using a light cone **106a**, with the return communication from the user network **104** to the central network **102** being via a standard telephone line. This may be the case when the Internet data is graphics and text, and the user data is credit card information, for example. This also may be the case when the Internet data is graphics and text, and the user data is user authorization information, for example.

Moreover, those skilled in the art will appreciate that, while the communication system **100** can involve the wireless exchange of extremely high-speed, broadcast, digital data, the communication system **100** can use other data rates. That is, the communication system **100** can communicate at data rates commensurate with the type service being provided, the quality of service requested, type of information transmitted and/or received, etc.

Downlink Transmission and Reception Structure

Figure 2 is a block diagram of illustrative central network **102** downlink transmission components. In this embodiment, the peripheral networks **105** send data for transmission to the user networks **104** via a central router/switcher **204**, a central downlink signal processor **206**, and a central transmit antenna **208**. A central system controller **210** controls the operation of the central router/switcher **204** and the central downlink signal processor **206**. Generally, data travels along the thick interconnection lines, while other commands, control signals, etc., travel along the thin interconnection lines. Data and other commands, control signals, etc., may also travel on thin and thick interconnection lines, respectively.

For purposes of explanation, only one central network 102 is described with respect to certain aspects of the embodiment of Figure 2. It is to be understood that the embodiment contemplates one or more central networks 102.

5 The central router/switcher 204 connects the central network 102 to the peripheral networks 105 and to the user networks 104, enabling data to be exchanged between them. The central router/switcher 204 can interconnect network interface controllers (NICs), disk controllers, graphic display adapters, etc., to the central network 102. For example, the central router/switcher 204 10 supports NICs implemented in a G-NIC Network Interface Card available from Packet Engines of Spokane, Washington, adapted from 830nm to 1550nm.

Other illustrative central router/switcher 204 implementations include well-known 10/100 Mbps Ethernet NICs with 64-bit Peripheral Component Interconnect (PCI) buses, which support either Windows NTTM or 15 the Digital UNIX[®] operating system. When the peripheral network 105 is the Internet, the central router/switcher 204 can support Internet points of presence (POPs).

The central router/switcher 204 in one embodiment is a fiber optic backbone that interconnects lower level network elements in the peripheral 20 networks 105 or the central networks 102. In that embodiment, and where the communication system 100 is a packet-switched network, the central router/switcher 204 is the main path for data packets. Packet-switched networks are described more fully below.

The central router/switcher 204 also interconnects the components 25 that transmit the light cones 106 and receive the collimated light beams 108. The central router/switcher 204 manages the routing of data through the communication system 100. For example the central router/switcher 204 divides the central network 102 into logical software-oriented sub-networks, enabling data traffic to be more efficiently routed. The central router/switcher 204 also 30 performs load balancing, partitioning, and statistical analysis on data traffic. The

central router/switcher 204 also determines routing priorities, and performs troubleshooting tasks. The central router/switcher 204 also selects the paths that data from the light beam 108 or data to the light cone 106 will take in the communication system 100. The central router/switcher 204 may dynamically 5 route data based on the quality of service required or the amount of data traffic in the central network 102.

In one embodiment, the central router/switcher 204 implements a link state routing algorithm that calculates routes based on the number of routers, transmission speed, delays, and route costs. This embodiment can be 10 implemented using an "open shortest path first" (OSPF) protocol running on a PowerRail 5200 Gigabit Ethernet routing switch available from Packet Engines. The central router/switcher 204 also includes several queues that hold data waiting to be routed.

The central downlink signal processor 206 receives the data to be 15 sent to the user networks 104 from the central router/switcher 204 and encodes, modulates, encrypts, buffers, and amplifies the data to produce a carrier whose frequency is in the visible or near-infrared region of the electromagnetic spectrum. A carrier with such a high frequency is sometimes referred to herein as an "optical signal," an "optical carrier," a "carrier," a "carrier signal," a 20 "lightwave signal," a "light cone," or a "light beam."

The central downlink signal processor 206 also shapes the carrier signal for transmission by the central transmit antenna 208. The structure and operation of the central downlink signal processor 206 is described in greater detail below with reference to Figure 4, including queuing of data waiting to be 25 processed.

The central transmit antenna 208 transmits the carrier into free space. For purposes of explanation, only one central transmit antenna 208 is described with respect to the illustrated embodiment of the invention. It is to be understood that the embodiment can contemplate one or more central transmit

antennas per local central network and one or more central networks per geographic location.

According to an embodiment, the central transmit antenna 208 transmits the carrier into free space using geometric optics, such as refractive, 5 reflective, diffractive, or holographic optics. Imaging geometric optics (IGOs) have the capability of making an image of an object. The image may either be a "real image" or a "virtual image." A real image is one that is cast on a screen, for example. A virtual image is viewed through an eyepiece.

To accomplish this task, an IGO has two properties: (1) Parallel 10 light rays passing through the optics are focused to a single point (the "focus"); and (2) Light rays incident from different angles are focused to different foci, all of which lie in a plane (the "focal plane"). A telescope, camera lens, shade projector, magnifying lenses, and contact lenses are examples of imaging geometric optics.

15 Non-imaging geometric optics (NGOs) do not satisfy at least one of the criterion necessary for an IGO. If one tries to observe an image created by NGOs, the image will either be "fuzzy" or nonexistent. Examples of NGOs are the Fresnel lenses used in front of motor vehicle headlights or the rippled "privacy" glass used in certain windows where privacy is required.

20 A diffraction grating is an example of an NGO suitable for implementing one embodiment of the invention. Of course, any diffraction grating suitable for focusing the desired wavelength that can focus the light cone 106 into a small enough spot could be used. In this embodiment, a diameter for the light cone 106 is 60 microns. Those skilled in the art will appreciate that the 25 particular diameter is dependent upon the desired data rate.

Although IGOs are adequate, they are expensive and the embodiment does not require all of their capabilities. Thus, one embodiment uses NGOs to maximize the utility of the system while minimizing the cost of the transmit and receive optics. A suitable non-imaging geometric optic operating in 30 the 1550nm range is available from Richardson Labs in Meridian, Idaho.

The central system controller **210** controls the operation of the central router/switcher **204**, and the central downlink signal processor **206**. The central system controller **210** can be implemented in hardware, software, or a combination of both hardware and software. In aspects that are implemented 5 using software, the software may be stored on a computer program product (such as an optical disk, a magnetic disk, a floppy disk, etc.) or a program storage device (such as an optical disk drive, a magnetic disk drive, a floppy disk drive, etc.). The central system controller **210** may also be custom software running on a composite of computers (or processors).

10 Figure 2A illustrates a flow diagram of a central system controller **210** transmit function **200** suitable for implementing the custom software running on a composite of computers. Operation of the transmit function **200** begins with step **211**, where control immediately passes to step **212**. In step **212**, the transmit function **200** determines which of its data queues advances next to send data to 15 the central downlink signal processor **206**. In step **214**, the transmit function **200** synchronizes encoding and multiplexing schemes. In an embodiment, a user system controller **310** (see, e.g., Figure 3) synchronizes encoding and multiplexing schemes with the user networks **104**. That is, the central system controller **210** performs handshaking with the user networks **104** to initiate a data 20 transfer.

In step **216**, the transmit function **200** determines the particular encoding required. Typically, the user networks **104** control the encryption scheme, while the central networks **102** control the multiplexing and encoding schemes. Thus, in an embodiment, the central controller **210** determines the 25 particular encoding required.

In step **218**, the transmit function **200** decides when a data packet is to be transmitted. In an embodiment, the central system controller **310** makes this decision. Operation of the transmit function **200** is complete following step **218**, as indicated by step **220**.

The output of the central networks 102 on the downlink are the light cones 106, which are transmitted into free space and received by the user networks 104. That is, each of the central networks 102 transmits data modulated on a shaped and diverging coherent or other light beam through free space.

Figure 3 is a block diagram of illustrative user network 104 downlink reception components. A user antenna 302 receives data transmitted from the central network 102, processes it using a user downlink signal processor 304, and sends the data to user equipment and devices 308, the user system controller 310, and/or any of the peripheral networks 105. For purposes of explanation, only one user network 104 may be described with respect to certain aspects of the embodiment shown in Figure 3. It is to be understood that embodiments of the invention contemplate one or more user networks 104.

As mentioned above, the user antenna 302 receives the light cones 106 from free space. The user antenna 302 receives the light cones 106 using an optical receiving antenna, which, in one embodiment, uses holographic optical elements. One embodiment uses well-known telescopes to receive the light cones 106. For example, the user antenna 302 can be a reflective telescope with a modified eyepiece to further confine the spot size of the received light. The user antenna 302 outputs the received light cones 106 to the user downlink signal processor 304.

The user downlink signal processor 304 receives the light cone 106 and decodes, demodulates, decrypts, and buffers it to separate the data from the carrier. The structure and operation of the user downlink signal processor 304 is described in greater detail below with reference to Figure 5.

The user input/output interface 306 interconnects the user equipment 308, the user system controller 310, and the peripheral networks 105. Recall that in one embodiment, the user network 104 is operated by a user that subscribes to send and receive data in a client-server environment, such that the central networks 102, the user networks 104, and the peripheral networks 105

connect "client" systems with "server" systems. The user input/output interface **306** interconnects the client systems with the server systems using appropriate signaling and protocols. In one aspect, the user input/output interface **306** supports well-known full-duplex operation and flow control common to client-server environments. In another aspect, the user input/output interface **306** supports Signaling Network Management Protocol (SNMP), which is a well-known method by which network management applications query a management agent using a supported Management Information Base (MIB). This embodiment manages virtually any network type, to include Non-Transmission Control Protocol (non-TCP) devices, such as IEEE 802.1 Ethernet bridges.

The user input/output interface **306** supports bidirectional encryption, with the ability to change keys as needed. The user input/output interface **306** also implements "challenge" and "reply" authentication when setting the keys. In this embodiment, the user input/output interface **306** has a unique serial number, even though it does not have a unique network address, which serial number can be used for encryption and other security features. The firmware on the subscriber input/output interface **306** also is protected from hacking.

The user equipment and devices **308** can be any of a variety of well-known equipment, such as gateways, local area networks, bridges, etc. The user equipment and devices **308** also can be any of a number of well-known user devices, such as printers, hard drives, graphical display adapters, televisions (TVs), TV set top boxes, telecommunication equipment, video conferencing equipment, and audio/visual equipment, such as home theater electronics, etc.

The user system controller **310** operation and structure are similar to the operation and structure of the central system controller **210**, in that the user system controller **310** controls the operation of the user downlink signal processor **304** and the user input/output interface **306**. The user system controller **310** likewise can be implemented in hardware, software, or a combination of both hardware and software. In embodiments that are implemented using software,

the software may be stored on a computer program product (such as an optical disk, a magnetic disk, a floppy disk, etc.) or a program storage device (such as an optical disk drive, a magnetic disk drive, a floppy disk drive, etc.).

5 The user system controller **310** may also be custom software running on a composite of computers (or processors). In one embodiment, the user system controller **310** is implemented in a token ring time-division multiplex (TDM) system.

10 Figure 3A illustrates a flow diagram of a data transmit routine **300** suitable for use with the user system controller **310** in this embodiment. The transmit routine **300** begins with step **311**, where control immediately passes to step **312** wherein the transmit routine **300** determines the type, amount, and rate of data to be transmitted.

15 In step **314**, the transmit routine **300** communicates the information gathered in step **312** to the central system controller **210**. In step **316**, the transmit routine **300** transmits data during the life of the token. In step **317**, the transmit routine **300** determines if no more data exist, and in step **318** returns a token to the central system controller **210**. If in step **318**, no more data returns a token to the central system controller **210**, the transmit routine **300** returns to step **312**.

20 In step **320**, if there is more data, the transmit routine **300** waits for the next token from the central system controller **210**, and then the transmit routine **300** returns to step **312**.

25 Figure 3B is a receive routine **350** that the user system controller **310** implements in the token ring TDM system embodiment. For example, in step **352**, the receive routine **350** receives a data packet and demodulates it. In step **354**, the receive routine **350** examines the data packet header, and determines if the data packet address matches a user system address.

30 In step **356**, the receive routine **350** determines whether the address of the data packet matches the user's system address. If the address is a match, then control of the receive routine **350** passes to step **358**, wherein the receive

routine 350 decrypts the data packet. In step 360, the receive routine 350 sends the data packet to the user's sub-network.

If, on the other hand, in step 356 it is determined that the data packet address does not match a user system address, operation of the receive 5 routine 350 passes to step 362, wherein the receive routine 350 dumps the data packet.

Figure 4 is a block diagram of illustrative central downlink signal processor 206 components. The illustrative central downlink signal processor 206 includes encoders 402, modulators 404, multiplexers 406, and power 10 amplifiers 408 that convert data into a carrier, and amplify the carrier for transmission in free space to the user networks 104.

The encoders 402 convert data into a representation of the data according to a set of rules or conventions specifying the way in which the signals representing the data can be formed, transmitted, received, and processed. In one 15 aspect, the encoders 402 encodes data and control signals into a high-speed data stream. Illustrative encoders 402 are implemented in a Media Access Controller (MAC) chip on Packet Engines' G-NIC. Of course, the encoders 402 can be implemented in any Ethernet card, switch, or repeater with the same encoding capabilities.

20 The modulators 404 modulate the light cone 106 according to the data to be transmitted on that light cone 106. There are several types of well-known modulation schemes used for communications (e.g., frequency modulation, phase modulation, phase-shift keying modulation, quadrature amplitude modulation, etc.), any of which are suitable for implementing 25 communication in the communication system 100. In one embodiment, the modulators 404 are implemented in well-known Ethernet Peripheral Component Interface (PCI) cards whose input and output are via optical fiber. In this embodiment, the modulators 404 use a well-known on-off keying (OOK) amplitude modulation scheme. The OOK amplitude modulation scheme is the 30 lowest cost modulation scheme currently available. Of course, the modulators

404 can be implemented in any Ethernet card, switch, or repeater with the same modulating capabilities. An embodiment uses the serializing/deserializing chip on Packet Engines' G-NIC to implement the modulation task, as well as to drive the laser.

5 The multiplexers **406** in one aspect are wavelength division multiplexers (WDMs) that establish optical channels by combining the wavelengths (or colors) into the light cone **106**. That is, the multiplexers **406** mix several channels at different wavelengths and output the wavelengths on the same light beam. In this aspect, the multiplexers **406** can be well-known passive
10 combiners or selective combiners. In another aspect, the multiplexers **406** are optical time division multiplexers (OTDM), or high density wavelength division multiplexers (HDWDM). Alternatively, multiplexers **406** can be implemented using coherent multi-channel heterodyne or homodyne detection techniques. In fact, any type of optical combiner that can perform the function of combining the
15 channels, such as fused filter couplers or Soliton multiplexers, also can be used to implement the multiplexers **406**. Of course, the invention is not limited by the particular type of multiplexing. For example, the channels can be combined into the light cone **106** using frequency, polarization, spatial position, polarity, space, algebraic transform methods, etc. An embodiment of the multiplexers **406** uses a
20 dense wavelength division multiplexer (DWDM) to select channels at International Telecommunications Union (ITU) standards for the 1530nm-1560nm range (approximately 0.8nm separation between channels).

The power amplifiers **408** may receive and amplify one or more wavelengths that will be present in the light cone **106**. The power amplifiers **408**
25 tolerate optical signals of many formats (or modulation schemes, such as polarity shift keying or amplitude shift keying) or bit rate (up to many Gbps), e.g., the power amplifiers **408** are transparent. In one embodiment of the invention, one geographic locality contains three central network stations. The signals from each of these central network stations are divided into 36 sectors. Each sector is
30 capable of carrying up to eight channels at 100 Mbps to 10 Gbps each, with an

overall local geographic capacity of up to 8.650 terabits per second (Tbps) (e.g., 3 stations x 36 sectors x 8 channels x 10 Gbps.) In an embodiment, the power amplifiers are erbium doped fiber optic amplifiers (EDFA), that amplify one or more wavelengths simultaneously, available from JDS Fitel Corporation in 5 Nepean, Ontario, Canada.

Figure 5 is a block diagram of illustrative user downlink signal processor 304 components. The embodiment user downlink signal processor 304 includes light cone detectors 502, user demodulators 504, user demultiplexers 506, and user decoders 508, which detect and separate data from the carrier in the 10 light cone 106 after it is received from free space by the user antenna 302.

The light cone detectors 502 detect and focus the light cone 106 onto a photodetector (not shown). The light cone detectors 502 may include a concentrator (not shown) which concentrates the light cone 106 and focuses it without loss. After detecting and focusing, the data on the light cone 106 is 15 amplified with a preamplifier (not shown), converted to serial form with a serializer (not shown), and protocol converted using a protocol converter (not shown). The preamplifier, serializer, and protocol converter are available in a G-NIC network interface card manufactured by Packet Engines, as described above with reference to the modulators 404. In this embodiment, the protocol 20 converter can either convert the modulation of the light cone 106 to a Gigabit Ethernet format or reduce it down to a 100 Mbit format. The detectors also include well-known pattern masks, such as diffraction gratings. The light cone detectors 502 output the light cone 106 to the user demodulators 504. Illustrative light cone detectors 502 are implemented in PIN diode in an off-the-shelf 25 1550nm transceiver unit manufactured by MRV Communications located at 20415 Nordhoff Street, Chatsworth, California 91311.

The user demodulators 504 demodulate the carrier using well-known demodulation techniques compatible with the modulation schemes used by the modulators 404. For example, in one embodiment, the user demodulators 30 504 are implemented in the Ethernet PCI cards.

The user demultiplexers **506** separate the wavelengths back into frequency-separated independent optical channels using techniques compatible with the multiplexers **406**. The demultiplexers **506** can be well-known passive splitters or selective splitters.

5 The user decoders **508** convert data from the representation of the data established by the encoders **402**. For example, the user decoders **508** decodes data and control signals from a high-speed data stream. An embodiment is implemented in a MAC chip on Packet Engines' G-NIC. Of course, the user decoders **508** can be implemented in any Ethernet card, switch, or repeater with
10 the same encoding capabilities. The user decoders **508** output decoded data to the user input/output interface **306**, which then makes the data available to the peripheral networks **105**.

15 Any or all of the components in the embodiments in Figures 2 and 4 or Figures 3 and 5 can be implemented on a single card, respectively. In one embodiment of the invention, the components in Figures 2 and 4 are implemented in a single card from Packet Engines. Similarly, the components in Figures 3 and 5 are implemented in a single card from Packet Engines. Of course, those skilled in the relevant art will appreciate that a particular physical location for the components in Figures 2 and 4 or Figures 3 and 5, respectively, is
20 not essential to practice the embodiment.

Downlink Transmission and Reception Operation

Figure 6 is a flow diagram of a downlink data transmission and reception process **600** performed by the central network **102** downlink transmission components, the user network **104** downlink reception components, and the peripheral networks **105**. The process **600** starts at step **602**, where control immediately passes to step **604**. In step **604**, the central router/switcher **204** receives data from the peripheral networks **105** designated for recipients in the user networks **104** or other central networks **102**.

5 In step 606, the central router/switcher 204 routes the data to the central downlink signal processor 206, where in step 608, the data is processed for transmission using the encoders 402, modulators 404, multiplexers 406, and power amplifiers 408. Following encoding, modulation, multiplexing, and amplifying, in step 610, the central transmit antenna 208 transmits the data into free space on the light cone 106.

10 In step 612, the user antenna 302 receives the light cone 106. The user downlink signal processor 304 processes the light cone 106 to remove the data from the carrier, and to separate out one or more of the channels. In step 10 614, the user input/output interface 306 sends that data to the peripheral networks 105, as indicated by step 616 and/or to the user equipment and devices 308, indicated by step 618, as appropriate. Following steps 616 and 618, operation of the process 600 is complete, as indicated by step 620.

Uplink Transmission and Reception Structure

15 Figure 7 is a block diagram of illustrative user network 104 uplink transmission components. The peripheral network 105 sends data for transmission to the central networks 102 via the user input/output interface 306 and/or the user equipment and devices 308 and sends it to a user uplink signal processor 702. The user uplink signal processor 702 outputs the data to the user 20 antenna 302 for transmission into free space on the collimated light beam 108, which is received by the central networks 102. The user uplink signal processor 702 is described more fully below with reference to Figure 9.

25 Figure 8 is a block diagram of illustrative central networks 102 uplink reception components. A central receive antenna 802 receives data transmitted from the user networks 104, processes the data using a central uplink signal processor 804, and routes the data to the peripheral networks 105 via the central router/switcher 204. The central system controller 210 controls the operation of the central router/switcher 204 and the central uplink signal

processor 804. The central uplink signal processor 804 is described more fully below with reference to Figure 10.

Figure 9 is a block diagram of illustrative user uplink signal processor 702 components. The illustrative user uplink signal processor 702 includes user multiplexers 902, user modulators 904, and user optical transmitters 906. The multiplexers 902 operate similarly to the multiplexers 406 in the central downlink signal processor 206, in that the multiplexers 902 can combine channels using WDM, OTDM, HDWDM, coherent multi-channel heterodyne or homodyne detection techniques, fused filter couplers, or Soliton multiplexers, for example.

The user modulators 904 operate similarly to the modulators 404 of the central downlink signal processor 206. For example, the user modulators 904 can implement several types of well-known modulation schemes used for communications. In one aspect of the invention, the user modulators 904 are implemented in well-known Ethernet PCI cards whose input and output are via optical fiber. The user optical transmitters 906 perform well-known optical signal processing on the data prior to output to the user antenna 302. An illustrative optical transmitter 906 includes a laser, an amplifier, and a telescope. This embodiment uses a telescope manufactured by Meade in Irvine, California, whose eyepiece has been adapted to allow a fiber optic element to be inserted into the eyepiece (so that the laser light can be sent into the telescope, and thus, transmitted into free space).

The output of the user optical transmitters 906 is sent to the user antenna 302, which transmits the multiplexed and modulated data as the collimated light beam 108 to the central networks 102. The central networks 102 receive the collimated light beam 108, process it using the central uplink signal processor 804, and send the data to any of the peripheral networks 105.

Figure 10 is a block diagram of illustrative central network 102 uplink components. As Figure 10 shows, the central receive antenna 802 receives the collimated light beams 108 from free space. The central receive

antenna 802 receives the collimated light beams 108 using an optical receiving antenna, which, in one embodiment of the invention, uses holographic optical elements.

The central uplink signal processor 804 includes collimated beam detectors 1002, central demodulators 1004, and central demultiplexers 1006. The collimated beam detectors 1002 detect and focus the collimated light beam 108 and provide spatial offsets to spatially separate and separately detect each collimated light beam 108 whether on identical or differing wavelengths. The collimated beam detectors 1002 can be similar to a two-dimensional array of photodetectors, each receiving a collimated light beam 108 from a different user network 104 or a lower level node. The collimated beam detectors 1002 output signals corresponding to the different collimated light beams 108. The central receive antenna 802 outputs the signals corresponding to the different received collimated light beams 108 to the central demodulators 1004. In one embodiment, the collimated beam detectors 1002 focus the collimated light beam 108 onto a 1500nm detector that detects data at rates in excess of 10 Mbps. Such detector is available from MRV Communications.

The central demodulators 1004 demodulate the carrier using well-known demodulation techniques compatible with the modulation schemes used by the user modulators 904. For example, in one embodiment, the user demodulators 1004 are implemented in well-known Ethernet PCI cards.

The central demultiplexers 1006 further separate the wavelengths back into spatially independent optical channels using techniques compatible with the user multiplexers 902. As such, the central demultiplexers 1006 can be well-known passive splitters or selective splitters. The central demultiplexers 1006 output data to the central router/switcher 204, which then makes the data available to the peripheral networks 105.

Uplink Transmission and Reception Operation

Figure 11 is a flow diagram of an uplink data transmission reception process 1100 performed by the central network 102 uplink transmission components, the user network 104 uplink reception components, and the 5 peripheral networks 105. The process 1100 starts at step 1102, where control immediately passes to step 1104. In step 1104, the user input/output interface 306 receives data from the peripheral networks 105 and routes the data to the user uplink signal processor 702.

10 In step 1106, the user uplink signal processor 702 processes the data for transmission using the user multiplexers 902, user modulators 904, and user optical transmitters 906. In step 1108, the user antenna 302 transmits the data into free space on the collimated light beam 108 into free space. In step 1110, the central receive antenna 802 receives the collimated light beam 108 from free space.

15 In step 1112, the central uplink signal processor 804 invokes steps 352 through 358 of the user system controller 310 receive function 350 (see, e.g., Figure 3B) and processes the collimated light beam 108 to remove the data from the carrier, and to separate out one or more of the channels.

20 In step 1114, the central router/switcher 204 sends that data to the peripheral networks 105, as indicated by step 1114 and/or to other central networks 102, indicated by step 1116, as appropriate. Following steps 1114 and 1116, operation of the process 1100 is complete, as indicated by step 1118.

25 It is noted that it can be less expensive to transmit from the user networks 104 to the central network 102 using the collimated light beam 108 as opposed to a shaped and diverging light cone 106, as is transmitted from the central network 102 to the user networks 104. For example, the collimated light beams 108 require less power. Moreover, transmitting using the collimated light beams 108 ensures that there is little interference between bidirectional light transmissions between the central networks 102 and the user networks 104.

Recall that the communication system **100** (see, e.g., Figure 1) also supports conventional methods of data communication. Accordingly, the communication network **100** can communicate at data rates commensurate with the medium of communication. For example, the communication system **100** can 5 transmit into free space at one data rate and receive via telephone lines at a different (e.g., lower) data rate.

Data Packet Structure

As described above, the communication system **100** uses packet-switching technology, in which data is divided into individual data packets before 10 transmission and routed through different network elements and may therefore arrive at different times or out of sequence. If received out of sequence, the individual data packets are reassembled at the intended destination.

Figure 12 illustrates a data packet **1200** suitable for use with the communication system **100**. The data packet **1200** includes a payload **1202**, 15 which typically is the data content. For example, the data content can be stock quotes, video/audio for a teleconference, etc. Those skilled in the art will appreciate that the particular payload may vary according to the application and may include information needed to facilitate reassembly of the data packets into the original data sequence.

20 The data packet **1200** also includes a header **1204**. The header **1204** typically includes a destination address **1206** that specifies the destination network element (or recipient) to which the data packet **1200** is to be routed. That is, the address **1206** specifies which central network **102**, user network **104**, 25 or peripheral network **105**, or their lower level nodes is the designated recipient of the particular data packet **1200**. When the recipients recognize their particular address **1206** in the data packet **1200**, the recipients accept the payload **1202** appended to the address **1206**.

The data packet **1200** also includes a cyclical redundancy check (CRC) **1208**, that is used to detect errors in the transmission of the data packet

1200. Other forms of error detection and correction may be used in place of, or in addition to, the CRC 1208. The data packet 1200 may also include error correction data under any conventional error correction method. The data packet 1200 also includes a miscellaneous portion 1210 for miscellaneous control or data information, such as for multicasting or broadcasting sessions. An illustrative data packet 1200 is a SONET data packet structure. An alternative is a standard Internet Protocol (IP) data packet, (e.g., IPv.4 (IPv.6) data packets with IEEE Ethernet 802.3 framing).

Sectorization

10 Recall that in one embodiment, data is sent from the central networks 102 to the user networks 104 using the light cones 106, and that the light cones 106 are shaped and diverging coherent light beams. Several shaped and diverging coherent light cones 106 are radiated in the substantially circular radiation pattern that illuminates any or all parts of the area surrounding the 15 central networks 102, much like a theatrical spotlight illuminates a stage. Parts of the illuminated areas can be emphasized, or made "brighter" than others, in order to deliver more signal strength to chosen areas. As is the case with the theatrical spotlight, the light cones 106 can be configured into any shape. The radiation pattern radii can be anywhere from one quarter meter to over three 20 kilometers.

Each central network 102 optically shapes the laser radiation patterns into the narrow radial sectors containing elevation sectors into which the wavelengths of infrared laser lights are transmitted. In one embodiment, the central downlink signal processor 206 shapes the laser beam into the desired 25 radiation pattern, with radial (or horizontal) sectors and/or elevation (or vertical) sectors further divided into several channels. Each channel is allocated particular wavelengths. A user can be assigned a wavelength such that the central networks 102 transmit a high-speed data stream to each user or group of users on the assigned wavelength. Each vertical sector and each horizontal sector may have

one or more channels of different wavelengths. Each of the channels may carry at least 10 Gbps of data. This arrangement accommodates a data transmitting capacity in excess of 20 Tbps and can service thousands of users.

Figure 13 illustrates an illustrative transmission point 1301 with 5 sectorization 1300. According to this embodiment, there are several horizontal subsectors, as represented by subsectors 1302a, 1302b and 1302c. Each sector may have vertical subsectors, as represented by subsectors 1306a and 1306b. Each vertical or horizontal subsector may be further divided into another subsector. Each horizontal subsector 1302a-c and/or vertical subsector 1306a-c 10 can have one or more wavelength channels (not shown).

When the communication system 100 communicates using the transmission point 1301 with the sectorization pattern 1300, the address in the data packet 1200 specifies the appropriate sector 1302 and wavelength channel.

It should be noted that the highly controllable shaped beams make 15 wavelength (or frequency) reuse a non-issue using the communication system 100. The sectors in the communication system 100 are strictly spatially separated, and so any channel can be used in any sector. This spatial reuse technique provides distinct advantages over common non-optical systems. Conventional frequency reuse schemes were necessary because of radiation 20 pattern side lobe interference caused by well-known right phrasing. Implementation of sectorization and shaped and diverging coherent light beams 106 avoids side lobe interference problems and, thus, avoids the need for frequency-reuse schemes. To accomplish this, the central transmit antennas 208 use central geometric antennas that are very large in terms of operating 25 wavelength (e.g., approximately eighty times the wavelength). Conversely, conventional radio antennas are approximately the same size as the carrier wavelength, so they cannot use geometric optics for their transmission sectors.

The transmission point 1301 with the sectorization pattern 1300 can generate several types of "footprints," as defined herein as an area of 30 coverage projected onto the buildings housing the user networks 104 by the beam

radiated from the transmission point 1301. In an embodiment, the transmission point 1301 has shaped sectorization designed to project a roughly circular footprint on the buildings housing the user networks 104.

Of course, the invention is not limited by the shape of the 5 footprints. Figure 14 illustrates examples of various suitable footprints 1402a-f generated by the central transmit antennas 208. While, in some cases, only one central transmit antenna 208 is illustrated per set of light cones 106 transmitted, it is to be understood that, for example, the central transmit antenna 208a includes 10 several telescopes, each capable of generating a uniquely shaped radiation pattern. For example, as one telescope of the central transmit antenna 208c generates a light cone 106d which produces a substantially circular footprint 1402d, another telescope of the central transmit antenna 208c generates a light cone (not shown) which produces a substantially heptagonal footprints 1402c.

Other footprints include elliptical, hexagonal, donut-shaped, 15 square, etc. For example, referring back to Figure 13, the subsector 1302a would generate an elliptical footprint. The subsector 1306a produces a hexagonal footprint. The subsector 1306b generates a donut-shaped footprint.

One purpose for overlapping radiation patterns is to deliver data at 20 different data rates or capacities to the same building. Of course, the particular radiation pattern used is determined by a number of factors, including the size and shape of the building that houses the user networks, for example, that ensure that the power in the optical signal is effectively utilized.

The communication system 100 also can include an optical repeater 1404, which receives, reconstructs, and amplifies either one way or 25 bidirectionally the light cones 106 and retransmits them to the user networks 104. The optical repeater 1404 compensates for dead spots in the transmitting radiation patterns. The optical repeater 1404 thus acts as an extension between central networks 102. The optical repeater 1404, while depicted as a single element, may contain multiple receiver-transmitter pairs that detect, reconstruct,

amplify, and retransmit the light cones **106** under the components discussed above with respect to Figures 2-6.

Figure 15 shows an illustrative topography **1500** surrounding the central networks **102**, by the sectorization pattern **1300**. The embodiment depicted in the topography **1500** includes three hexagonal light propagation patterns **1502a**, **1502b**, and **1502c**. In this embodiment, each sectorization pattern **1300** has 36 sectors, where one sector in each sectorization pattern **1300** is represented by the sectors **1502a₁**, **1502b₁**, and **1502c₁**, respectively. An alternative embodiment has 60 radial sectors, each with six degrees of azimuth, and five elevation sectors, each with eight channels accommodating a data rate from 10 Mbps to 10 Gbps. Still another embodiment divides a radiation pattern into 120 three-degree sectors, with each sector delivering 10 Mbps to 10 Gbps to the user networks **104**.

Figure 15 also depicts several central networks **102** interconnected by ultra-wide bandwidth optical backbone links **1510**. The optical backbone links **1510** also allow interconnection with Internet POPs, major carriers, the PSTN, or other peripheral networks **105**.

The systems, methods, and interconnected devices for networked, high-speed bi-directional data communication through free space described herein are particularly suitable for use in foggy weather conditions, where optical signals are susceptible to attenuation. A study in London, England of point-to-point laser communication produced data on reliability that, when combined with a historical database, produced a weather database with forty years of data collected on an hourly basis. With this kind of information, the parameters of the communication system **100** can be modified to compensate for certain atmospheric conditions. For example, the power output of the central transmit antennas **208** and/or the user antennas **302**, radii of the cells, sensitivity of the detectors and/or the data rate can be increased or decreased as appropriate. Similarly, the size of the antennas can be adjusted to compensate for any anticipated attenuation of the signal.

The coverage area of the radiation pattern generated by the central transmit antenna **208** also can be predetermined by design to anticipate atmospheric conditions. For example, in the city of Seattle, Washington which is known for foggy conditions typically causing strong attenuation, the radiation 5 patterns can be reduced to one quarter kilometer, as opposed to the two kilometer radiation patterns appropriate for sunny locations.

Other suitable modifications include changing the shape of the light cones **106**, changing the tint of the windows through which the light beams/light cones are transmitted, changing the optical amplifier strengths. etc.

10 Broadcast and Multicast Operation

Recall that the communication system **100** broadcasts and multicasts data from the central networks **102**. During broadcast operations, the data is transmitted from any one of the central networks **102** or their lower level nodes to all user networks **104** and/or all peripheral networks **105** and/or their 15 lower level nodes, for example. Any well-known broadcast addressing scheme is suitable for implementing this embodiment.

During point-to-multipoint multicast communication, selected user networks **104**, peripheral networks **105**, and/or their lower level nodes receive data. This embodiment is ideal in situations where identical data content is 20 desired to be transmitted to a particular group of user networks **104** and/or peripheral networks **105** substantially simultaneously (e.g., during video teleconferences).

In this embodiment, the miscellaneous portion **1210** of the data packet **1200**, depicted in Figure 12, includes a multicast session identifier (not 25 shown) that identifies a multicast session and a set of users that are the recipients of the transmission during the particular multicast session. The content of the transmission that one member of a multicast session group receives is substantially the same as the high-speed data that another member of the multicast session group receives during a particular multicast session.

Each multicast session identifier is associated with a set of unique addresses. There is a unique address for each recipient of the multicasted data. The central network 102 transmits the multicast session identifiers to the recipients, which use the association to determine the unique address for each of 5 the recipients associated with the set of unique addresses. The central network 102 adds the unique addresses for the recipients to each data packet 1200 received from the other interconnected networks prior to transmitting the received data packet 1200 to the specified set of recipients.

Each central network 102 also may include a plurality of multicast 10 session identifier translation tables to translate multicast session identifiers into unique addresses for the subscribers. There may be one or more multicast sessions identified by multicast session identifiers. Each of the multicast session identifiers is associated with a set of unique addresses representing a set of users. The central network 102 includes at least one translation table to correlate the 15 multisession identifiers with each set of unique addresses for the set of selected recipients.

Table 1 is an example of a multicast session identifier table suitable for use with one embodiment of the invention. Table 1 lists example multicast sessions (1 through 4), functional group identifiers (A through D) for the 20 functional groups associated with a particular multicast session, sets of addresses for the particular recipients in the particular functional group, and recipients associated with the unique addresses designated to receive transmissions during the particular multicast session. Note that the multicast sessions may have overlapping recipients such that one recipient may be included in the multicast session "1" as well as in the multicast session "2." Note that the recipients are 25 designated 104a through 104d to represent either several user networks 104 or several of their lower level nodes.

Table 1

| Multicast Session | Functional Group ID | Unique Addresses | Recipients |
|-------------------|---------------------|--|------------------------------|
| 1 | A | 0112.3456.7890 0223.4567.8901 0334.5678.9012 0445.6789.0123 | 104a 104b 104c 104d |
| 2 | B | 0445.6789.0123 0223.4567.8901 0334.5678.9012 | 104d 104b 104c |
| 3 | C | 0445.6789.0123 0112.3456.7890 | 104d 104a |
| 4 | D | 0445.6789.0123 0334.5678.9012 | 104d 104c |

Figure 16 is a flowchart showing an illustrative multicast process 1600. The multicast process 1600 starts at step 1602, where control immediately passes to step 1604. In step 1604, one of the peripheral networks 105 transmits high-speed data and a multicast session identifier to the central network 102. For example, according to Table 1, during the first multicast session, one of the peripheral networks 105 transmits the functional group identifier "A" to the central network 102.

In step 1606, the central network 102 receives the high-speed data and the multicast session identifier. In step 1608, the central network 102 determines the functional group associated with the multicast session by looking in its translation table. In step 1610, the central network 102 determines the set of recipients in the functional group.

In step 1612, the central network 102 determines the unique address of each recipient in the set of recipients in the functional group. For example, the central network 102 looks in its multicast session identifier translation table to determine the unique address for the sets of recipients associated with the functional group identifier "A." In step 1614, the central network 102 adds the unique address for the sets of recipients to the high-speed data received from the central network 102 and transmits the resulting high-speed data to the recipients 104a-d. Once the high-speed data has been transmitted

from the central network 102 to the recipients 104a-d, the multicast process 1600 ends, as indicated by step 1616.

It is noted that the multiplexing and demultiplexing schemes used by the central networks 102 differ from the multiplexing and demultiplexing 5 schemes used by the user networks 104 in that the central networks' 102 multiplexing and demultiplexing schemes have additional levels of address translation to accommodate routing of incoming IP addresses to the appropriate addressees. The additional routing is implemented in the central router/switcher 204.

10 All of the optics described herein can be enclosed in a "black box," such as a Faraday cage, to isolate the optical components from outside interference such as extraneous optical frequencies. Enclosing the optics in a black box is less expensive and simpler than conventional methods for eliminating outside interference.

15 Recall that the central router/switcher 204 connects the central network 102 to the peripheral networks 105 and to the user networks 104, enabling data to be exchanged between them. Recall further that the central router/switcher 204 supports NICs implemented in a G-NIC Network Interface Card available from Packet Engines. Figure 17 shows an illustrative central 20 router/switcher 204 implemented on the G-NIC Network Interface Card.

The central router/switcher 204 in this embodiment includes a gigabit uplink port 1702 and up to two server ports: an optional gigabit server port 1704 and a 10/100 Ethernet server port 1706. The central router/switcher 204 also includes a glue logic and memory control processor 1707. The gigabit 25 uplink port 1702 receives data packets 1200 on its input and sends the data packets 1200 to the output of whichever server port is active. At the same time, the central router/switcher 204 sends any data packets 1200 received on an input of the active server port to the output of the gigabit up link port 1702.

It is noted that all data packets 1200 coming from either server port 30 1704, 1706 will be sent to the gigabit uplink port 1702, but the data packets 1200

coming from the gigabit uplink port 1702 destined for either server port 1704, 1706 will be filtered by the glue logic and memory control processor 1707. That is, only the data packets 1200 meeting the filter requirements will be sent to the appropriate server port 1704, 1706. At a minimum, the gigabit uplink port 1702 5 filters received data packets 1200 by accepting only the data packets 1200 destined for a particular Ethernet address. In this embodiment, the gigabit uplink port 1702 also accept broadcast data packets and multicast data packets. In one embodiment, filtering may be performed by a host computer system under the purview of a user network 104.

10 The central router/switcher 204 in another embodiment is connected from one of the server ports directly to a matching port on a host computer system located at a user network 104. In this embodiment, if the gigabit uplink port 1702 uses the same Ethernet address as the port on the host computer system, the central router/switcher 204 supports only that host on its 15 gigabit uplink port 1702. This is because the Ethernet address of the host computer system is programmed into the central router/switcher 204.

10 In another embodiment, the central router/switcher 204 "auto-discovers" its Ethernet address from the data packets 1200 seen on the server ports. Alternatively, central router/switcher 204 is preprogrammed with the same 20 Ethernet address as an Ethernet card assigned to the host computer system.

Some Additional Features

The communication system 100 increases both the transmit and receive communication capacity of conventional communication systems. The greater capacity is important to note because standard telephone lines are being 25 pushed to their limit and can provide only approximately 60 Kbps of data network connection. Other network alternatives have been developed but have their limitations as well. For example, ISDN, once thought to be the wide area networking solution of choice, is limited to 128 Kbps. The newly touted ADSL services are limited to eight Mbps and are asymmetric (fast in only one

direction—the downlink). Existing personal computers (PCs) have the ability to network locally at over 100 Mbps, leaving these wide area network technologies extremely inadequate.

The most publicized attempt to break the bandwidth bottleneck 5 incorporates satellites in low-Earth orbits (LEO). These satellite networks can obtain data down-link rates from 1.5-28 Mbps. The cost to deploy these systems, however, ranges into billions of dollars and requires years to deploy.

Fiber optic and LMDS are also available and planned technologies in the telecommunication market. While LMDS is thought to require only 25 10 percent of the capital cost of deploying optical fiber, there appears to be an upper limit from four to six Gbps of total traffic capacity per four kilometer wide cell, which places a significant limit on system growth. For example, in an area twice the size of downtown Seattle's business core, only 40 to 60 concurrent customers could have 100 Mbps access. In contrast, the optical communication system 100 15 can potentially serve up to thousands of such concurrent connections.

The communication system 100 may only require 30 percent of the capital cost of an LMDS (or approximately eight percent of fiber) without the two Gbps limitation of total capacity per cell. Recall that the communication system 100 has the ability to communicate at 2.5 Gbps duplex or 1.25 simplex 20 per channel, and its overall capacity per system may be in excess of two Tbps. This capacity is 1,000 times higher than LMDS and translates to significantly lower infrastructure costs, and the ability to undercut competitors' pricing and/or outperform competitive offerings.

The communication system 100 accomplishes these staggering 25 speeds/volumes by combining wireless, fiber, and networking concepts to form a unique network that has the ability to deliver terabits of information around the world in a very timely and cost-efficient manner.

The communication system 100 antennas are similar in size and shape to a small dish antenna of the type that can be found on many rooftops.

However, the antennas may be placed behind a window glass, making deployment much easier than rooftop-only installations.

While the technology that the communication system 100 implements allows for a radiation pattern radii well over three kilometers, for 5 urban cores, however, the central networks 102 can be much smaller and dependent upon the geography of the region as well as the building size and building location. Moreover, as described above, the communication system 100 has a very advantageous channel re-use property, allowing significantly lower costs, significantly higher capacities, and greater bandwidth.

10 Using a very simple example, assume one central network 102 is sectored into 120 three-degree sectors, with each sector delivering 100 Mbps to 2.5 Gbps. In this very simple example, this single central network 102 has the ability to deliver 300 Gbps to a large number of users. With the addition of additional channels per sector, the data throughput increases significantly. By 15 using eight channels per sector, the optical communication system 100 has the ability to effectively increase the data throughput on a single local central network 102 to 2.4 Tbps. Such a central network 102 could supply 100 Mbps service to 24,000 concurrent users. This far exceeds conventional communication systems. The only close competitor is LMDS, which currently is 20 limited to about four Gbps per cell site.

Many of the components in the communication system 100 may be implemented using hardware, software, or a combination of hardware and software, and may be implemented in a computer system or other processing system. In aspects where the invention is implemented using hardware, the 25 hardware components may be Application-Specific Integrated Circuits (ASICs), or a hardware state machine. In aspects that are implemented using software, the software may be stored on a computer program product (such as an optical disk, a magnetic disk, a floppy disk, etc.) or a program storage device (such as an optical disk drive, a magnetic disk drive, a floppy disk drive, etc.). That is, 30 software may be available from a removable disk or from code downloaded on a

hard drive. Moreover, the software can include code stored in a module such as a Read-Only Memory (ROM), Programmable ROM (PROM), or any variation of an Erasable PROM (e.g., EPROM, EEPROM, etc.).

According to one embodiment, the communication system **100** uses well-known Time Division Multiple Access (TDMA) techniques. In TDMA, each user network **104** is assigned one or more TDMA time slots based on the allocated wavelength (or data rate), and the networks communicate with each other during the designated TDMA time slots. When the communication system **100** uses TDMA technology, the communication system **100** can multiplex several user networks **104** on one TDMA channel, using a well-known diffraction grading (or pattern mask) to receive only certain bits from the data stream for each user network **104**.

A resource manager (not shown) coordinates assignments of TDMA time slots. The resource manager negotiates for a channel (e.g., a time slot at a particular frequency).

Interconnection of the arrangement of the light cones **106** and the collimated light beams **108** may be done using standard Internet protocols, such as "open shortest path first" (OSPF), which is a link state routing algorithm that is used to calculate routes based on the number of routers, transmission speed, delays, and route costs. Interconnection of the light cones **106** and the collimated light beams **108** can also be accomplished using other well-known routing algorithms.

Figure 18 shows an alternative embodiment of the communication system **100**. This alternative embodiment uses a multi-access receiver/transmitter (MART) **1802** for both transmission and reception. The central network **102** is connected to the MART **1802** by a transmission link **1800**. The transmission link **1800** is a hardwire link, such as a telephone line or fiber optic cable, but it is also possible to use a wireless link (e.g., radio frequency, laser light, etc.). Additionally, while Figure 18 depicts the central network **102**

and the MART 1802 as being separated, remote components, it is appreciated that the MART 1802 can be within the central network 102.

The MART 1802 includes an array 1804 of central transmit antennas 208 and central receive antennas 802. The central transmit antennas 5 208 in Figure 18 are coaxially located at the center of their respective central receive antennas 802. Other modifications are possible. For instance, the central transmit antennas 208 may be located near (e.g., separated from) their respective central receive antennas 802, instead of being coaxially located. It is also possible to use the same optical device to transmit and receive if wavelength 10 separation between the transmitted and received signals is adequate.

Downlink transmission from the central network 102 to the user network 104 and/or the peripheral network 105 uses a concept of splitting a single broadcast beam into several light cones 106, with each light cone 106 having all of the information present in the single broadcast beam. First, one or 15 more power amplifiers 408, such as a 500 mW EDFA, in the MART 1802 splits the single broadcast beam received through the transmission link 1800 and provides the individual signals to respective central transmit antennas 208. The central transmit antennas 208 then transmit the individual signals as light cones 106 to the user network 104 and/or the peripheral network 105. The array 1804, 20 or the individual central transmit antennas 208 and central receive antennas 802, can be mounted, for example, onto one or more gimbal structures to direct the transmitted light cones 106. Available optics are used to focus and direct the light cones 106 as necessary.

The embodiment shown in Figure 18 allows one or more light 25 cones 106 to be focused on particular receivers in the user network 104 or the peripheral network 105. That is, instead of transmitting to an entire building, separate light cones 106 can be transmitted to particular receivers in the building. Further, the separate light cones 106 can have different power, such that light cones 106 having greater power are transmitted to receivers that are farther away 30 or are behind darkly tinted windows, and light cones 106 having less power are

transmitted to closer-range receivers. Also, the MART 1802 can transmit to more than one building, such that some light cones 106 are transmitted to one building and other light cones 106 are transmitted to other buildings. By adjusting the power level of the transmission and pointing the central transmit 5 antennas 208 in the appropriate direction, it is thus possible to "link" several buildings and at greater distances from the same MART 1802. To maximize efficiency, a given power output of the power amplifier 408 can be apportioned between the various light cones 106, such that light cones 106 requiring less power are reduced in power while the other light cones 106 requiring more 10 power are correspondingly increased in power.

Further, the scope of transmission coverage of the MART 1802 is easily changed by adjusting the number of splits in the power amplifier 408. A sector of up to a full hemisphere is possible by splitting a single broadcast signal with the power amplifier 408 and providing central transmit antennas 208 in each 15 quadrant.

The MART 1802 can also receive collimated light beams 108 from the user network 104 and/or peripheral network 105. A plurality of collimated light beams 108 transmitted from individual transmitters in the user network 104 and/or the peripheral network 105 are received by the central receive antennas 20 208 in the MART 1802. Like the transmission from the MART 1802 described above, the uplink transmission of collimated light beams 108 from the user network 104 and/or the peripheral network 105 to the MART 1802 allows multiple signals to be linked at the MART 1802.

Many possible design parameters can be used for the embodiment 25 shown in Figure 18. For instance, a 12° sector can project a light cone 106 of 100 meters in diameter at a distance of 500 meters. A three mrad beam can project a light cone 106 having a diameter of 1.5 meters at a distance of 500 meters. Using the same transmit power and assuming zero losses during the split, a three mrad beam can be projected at each of 4,444 customers and have the 30 same power density as the 12° sector. Alternatively, service can be provided to

100 customers, with a 16 dB of link margin for each. The increased link margin can be used to reduce the size and costs of each customer's receiver.

Although specific aspects of, and examples for the invention are described herein for illustrative purposes, various equivalent modifications are possible within the scope of the invention and can be made without deviating from the spirit and scope of the invention, as will be recognized by those skilled in the relevant art. For instance, although a laser has been described herein as generating the various light beams and light transmissions, other light-generating devices, such as light-emitting diodes (LEDs), can be used. Also, although the 10 collimated light beams **108** are used in the network uplink components (*see, e.g.*, Figures 7-10) and the light cones **106** are used in the network downlink components (*see, e.g.*, Figures 2 and 3-5) in the embodiments described herein, it is to be appreciated that in some embodiments, the network uplink components can use the light cones **106** or the network downlink components can use the 15 collimated light beams **108**. Further, several channels (*e.g.*, frequency domain) can be used in the uplink as well, with appropriate coordination between a user and a central node.

The teachings provided herein of embodiments of the invention can be applied to optical links made functional by any standard network 20 interconnection. For example, the G-NIC Network Interface Card (*see, e.g.*, Figure 2) can be implemented in PCs. Further, one or more components or functions of the communication system **100** can be embodied in a computer network, computer-readable media (such as magnetic cassettes, digital video disks, CD-ROMs, Bernoulli cartridges, random access memories (RAM), ROMs, 25 smart cards, etc.) and their associated devices. One or more components or functions of the communication system **100** can be embodied in computer-readable or computer-executable instructions such as program modules or macros executable by a microprocessor or by a computer. How to implement these types of features can be understood by one skilled in the art based on the detailed 30 description provided herein.

These and other changes can be made to the invention in light of the above-detailed description. In general, in the following claims, the terms used should not be construed to limit the invention to the specific aspects disclosed in the specification and claims, but should be construed to include all 5 optical communication systems that operate under the claims to provide, *inter alia*, high-speed optical data communication. Accordingly, the invention is not limited by the disclosure, but instead the scope of the invention is to be determined entirely by the following claims, which are to be construed in accordance with established doctrines of claim interpretation.

CLAIMS

What is claimed is:

1. A communication system, comprising:
 - a peripheral node configured to transmit at least one first information signal and configured to receive a second information signal;
 - at least one central node configured to receive the first information signal from the peripheral node and transmit the received first information signal through free space modulated on a first light beam, configured to transmit the second information signal to the peripheral node, and configured to receive at least one third information signal from free space modulated on a second light beam; and
 - at least one user node configured to receive the first light beam and demodulate the modulated first information signal from free space, and configured to transmit the third information signal through free space modulated on the second light beam.
2. The communication system of claim 1 wherein the first light beam comprises a shaped and diverging laser beam and the second light beam comprises a collimated light beam.
3. The communication system of claim 1 wherein the at least one central node includes:
 - a plurality of central nodes forming a central network, each central node configured to transmit a plurality of the first information signals modulated on shaped and diverging coherent light beams through free space; and
 - wherein the at least one user node includes a plurality of user nodes forming a user network, each user node configured to receive the plurality of first information signals modulated on shaped and diverging coherent light beams through free space. and

wherein the central nodes are configured to transmit to the user nodes in a node-to-node, node-to-multipoint, multipoint-to-node, or multipoint-to-multipoint manner.

4. A method for transmitting data between a central point and at least one user, the method comprising:

at the central point, modulating data and at least one user address on a light beam;

at the central point, transmitting the light beam through free space;

demodulating the light beam and retrieving the data and the at least one user address;

routing the data to the user according to the user address; and

transmitting data from the user to a central point.

5. The method of claim 4 wherein the light beam on which the data and the at least one user address is modulated comprises a shaped and diverging light beam.

6. The method of claim 4 wherein the light beam on which the data and the at least one user address is modulated comprises a shaped, diverging, and coherent light beam.

7. The method of claim 4 wherein the light beam on which the data and the at least one user address is modulated comprises a laser beam.

8. The method of claim 4, further comprising:

modulating the data and several user addresses on a light beam;

routing the data to the several user addresses; and

transmitting data from at least one of the users to a central point through free space or via at least one telephone line.

9. The method of claim 4, further comprising transmitting the light beam through free space to several user addresses in a point-to-point, point-to-multipoint, multipoint-to-point, or multipoint-to-multipoint manner.

10. A communication system, comprising:

a central node configured to transmit through free space an information signal modulated on a diverging coherent light beam; and

a user node configured to receive from free space the diverging coherent light beam and automatically process the modulated informational signal, wherein the diverging coherent light beam, as received at the user node, has different dimensions diverging coherent light beam at the central node.

11. The communication system of claim 10, further comprising:

a plurality of central nodes each configured to transmit through free space a plurality of information signals modulated on a plurality of diverging light beams; and

a plurality of user nodes each configured to receive from free space the informational signals modulated on diverging light beams, wherein the central nodes are configured to transmit to the user nodes in a broadcast, simulcast, or multicast manner.

12. The communication system of claim 10 wherein the central node is configured to transmit through free space to the user node in one of a broadcast or multicast manner.

13. The communication system of claim 10, further comprising a peripheral node configured to transmit the information signal to the central node for modulation.

14. The communication system of claim 10, further comprising a common carrier, virtual node, or an area node configured to transmit the informational signal to the central node for modulation.

15. The communication system of claim 10 wherein the central node and the user node are interconnected using synchronous optical network (SONET) architectures.

16. The communication system of claim 10, further comprising a peripheral node, wherein the central node, user node, and peripheral node are interconnected using synchronous optical network (SONET) architectures.

17. The communication system of claim 10 wherein the central node and the user node are interconnected using gigabit Ethernet architectures.

18. The communication system of claim 10, further comprising a peripheral node, wherein the central node, user node, and peripheral node are interconnected using gigabit Ethernet architectures.

19. The communication system of claim 10 wherein the diverging light beam comprises a shaped, coherent infrared laser operating at a wavelength of approximately 1550nm.

20. The communication system of claim 10 wherein the diverging light beam comprises a shaped coherent infrared, near-infrared, or visible light laser beam.

21. The communication system of claim 10 wherein the light beam comprises a shaped and coherent diverging light beam.

22. The communication system of claim 10, further comprising a diffraction grating, beam shaping lens, or a holographic optical element.

23. The communication system of claim 10, further comprising a beam shaping optic that horizontally shapes the diverging light beam.

24. The communication system of claim 10, further comprising a beam shaping optic that vertically shapes the diverging light beam.

25. The communication system of claim 10 wherein the information signal further comprises at least one data packet having a header and a payload, the header specifying at least one of the user nodes and the payload comprising high-bandwidth data.

26. A communication system, comprising:
at least one user node configured to transmit an information signal through free space modulated on a light beam; and
a central node configured to receive the light beam from free space and to demodulate the information signal from the light beam, and to send the information signal to a peripheral node.

27. The communication system of claim 26 wherein the light beam comprises a collimated light beam.

28. The communication system of claim 26 wherein the light beam comprises a shaped and diverging light beam.

29. The communication system of claim 26 wherein the user node is configured to transmit the information signal modulated on a collimated laser beam

and the central node is configured to receive the information signal modulated on a collimated laser beam.

30. The communication system of claim 26 wherein the user node further comprises an antenna having a diffraction grating, beam shaping lens, or a holographic optical element.

31. The communication system of claim 26 wherein the light beam comprises a light beam in a substantially 1550 nm region of a light spectrum.

32. An apparatus configured to transmit an optical carrier through free space to a plurality of user nodes, comprising:

an input port configured to receive an information signal;

a radiant energy generator configured to generate an optical carrier;

a signal processor, coupled to the radiant energy generator and the input port, configured to process and combine the optical carrier with the information signal; and

an antenna, coupled to the signal processor, configured to produce a shaped and diverging radiant energy and to transmit the combined optical carrier and information signal on the shaped and diverging radiant energy into free space.

33. The communication system of claim 32, further comprising a multiplexer configured to combine several information signals from several wavelength channels into the optical carrier.

34. The communication system of claim 32, further comprising an optical time division multiplexer (OTDM), high density wavelength division multiplexers (HDWDM), a coherent multi-channel heterodyne detector, a coherent multi-channel homodyne detector, a fused filter coupler, a Soliton multiplexer, a frequency combiner, a polarity combiner, a spatial combiner, or an algebraic transform

combiner configured to combine several information signals from several channels into the optical carrier.

35. The communication system of claim 32, further comprising a power amplifier, an erbium-doped fiber amplifier, or a ytterbium-doped fiber amplifier configured to amplify the optical carrier.

36. The communication system of claim 32, further comprising an encoder configured to encode data and control signals into the information signal.

37. A method for transmitting and receiving data between a user point and one of a plurality of peripheral points via a central point, the method comprising:

at the user point, modulating data and at least one peripheral point address on a collimated light beam;

at the user point, transmitting the collimated light beam through free space to the central point;

at the central point, demodulating the collimated light beam and retrieving the data and the peripheral point address; and

routing the data to the peripheral point address.

38. The method of claim 37, further comprising modulating the data and the peripheral point address on a collimated laser beam.

39. The method of claim 37, further comprising:

modulating the data and several peripheral point address on several collimated light beams; and

routing the data to the several peripheral point addresses.

40. The method of claim 37, further comprising transmitting the light beams through free space to the peripheral points in a point-to-point, multipoint-to-point, or multipoint-to-multipoint manner.

41. A method for transmitting data, comprising:
combining several data channels into a data stream;
modulating the data stream on at least one diverging light beam;
transmitting the diverging light beam through free space;
demodulating the diverging light beam and retrieving the data stream;

and

separating the several channels of data from the data stream.

42. The method of claim 41, further comprising:
modulating the data stream on a shaped and diverging light beam; and
routing the several data channels to several user devices.

43. The method of claim 41, further comprising modulating the data stream on a shaped, diverging, and coherent light beam.

44. The method of claim 41, further comprising modulating the data stream on at least two laser beams having different wavelengths transmitted over substantially a same diverging cone through free space.

45. The method of claim 41, further comprising transmitting the diverging light beam through free space to several users in a point-to-point, point-to-multipoint, multipoint-to-point, or multipoint-to-multipoint manner.

46. The method of claim 41, further comprising encrypting data on several data channels.

47. The method of claim 41, further comprising encoding data on several data channels.

48. An apparatus for receiving an information signal, comprising:
an antenna configured to receive from free space an optical carrier having an information signal modulated on a shaped and diverging coherent light beam;
a signal processor, coupled to the antenna, configured to process and demodulate the shaped and diverging coherent light beam to separate the information signal from the optical carrier; and
an output port, coupled to the signal processor, configured to send the information signal to at least one device.

49. The communication system of claim 48 wherein the antenna includes at least one holographic optical element or a telescope.

50. The communication system of claim 48 wherein the signal processor includes at least one shaped and diverging coherent light beam detector, a demodulator, a demultiplexer, or a decoder.

51. The communication system of claim 48 wherein the interface is configured to send the informational signal to one of a signaling node management protocol (SNMP) device, a transmission control protocol (TCP) device, a gateway, a local area node, a bridge, a printer, a hard disk drive, a graphical display adapter, a television, a television set top box, telecommunication equipment, video conferencing equipment, audio/visual equipment, or home theater electronics.

52. A method of transmitting and receiving data, comprising:

receiving encoded data and a multicasting session identifier, the multicasting session identifier indicating a group of recipient user points selected from among a plurality of user nodes configured to receive the encoded data;

transmitting the encoded data and a multicasting session identifier on a shaped and diverging light beam via free space to the plurality of user nodes;

receiving the shaped and diverging light beam from free space; and

decoding the encoded data.

53. The method of claim 52, further comprising appending to the encoded data a group of unique user node addresses respectively representing the group of recipient user nodes.

54. The method of claim 52, further comprising modulating the encoded data and the group of unique user node addresses on a shaped and diverging light beam.

55. A data communication system, comprising:

a transmitter configured to transmit an informational signal through free space modulated on a shaped and diverging coherent light beam, wherein the coherent light beam is sufficiently divergent to be received by a plurality of spatially separated receivers; and

a set of receivers, selected from among the plurality of receivers, configured to receive the shaped and diverging coherent light beam from free space and decode the modulated informational signal.

56. The system of claim 55 wherein each receiver in the set of receivers has a unique receiver address and the transmitter is configured to add the unique receiver address to the informational signal before transmitting informational signal to the set of receivers.

57. The system of claim 55 wherein the transmitter is configured to transmit the informational signal using data packets having a multicasting session identifier associated with high-speed data and a set of selected receivers.

58. The system of claim 55, further comprising a storage device, coupled to the transmitter, configured to store a multicasting session identifier translation table to translate first and second multicasting session identifiers into unique receiver addresses of first and second sets of receivers, respectively.

59. A method for free space optical data communication, comprising:
receiving at an antenna, a shaped and diverging coherent light beam transmitted through free space, wherein the light beam has an information signal modulated thereon, and wherein a cross-sectional area of the received diverging coherent light beam as received at the antenna is substantially greater than an area of the antenna; and

demodulating and recovering the information signal from the shaped and diverging coherent light beam.

60. The method of claim 59 wherein the information signals comprises at least one video signal, audio signal or data signal.

61. The method of claim 59 wherein the high-speed information signals comprises at least one video signal at a first data rate, an audio signal at a second data rate, or a data signal at a third data rate.

62. A data communication system, comprising:
a transmission node having at least one radiant energy generator that generates information bearing radiant energy beams over several sectors,
wherein each subsector comprises a channel, and

wherein each channel operates at substantially the same wavelength.

63. The data communication system of claim 62 wherein the sectors comprise radial sectors.

64. The data communication system of claim 62 wherein the sectors comprise elevation sectors.

65. The data communication system of claim 62 wherein the sectors comprise radial sectors, wherein each sector includes at least two subsectors, and wherein the subsectors comprise elevation subsectors.

66. The data communication system of claim 62 wherein the sectors include at least one elliptically-shaped sector, hexagon-shaped sector, donut-shaped sector, elliptically-shaped subsector, hexagon-shaped subsector, or donut-shaped subsector.

67. The data communication system of claim 62 wherein each channel operates approximately at a 1550nm wavelength.

68. The data communication system of claim 62 wherein a first channel operates at a first wavelength and a second channel operates at a second wavelength.

69. The data communication system of claim 62 wherein the transmission node comprises a telescope.

70. A method of transmitting data comprising:
modulating at least one information signal on at least one carrier; and

substantially simultaneously transmitting the modulated information signal along a plurality of vertically differentiated sectors.

71. The method of transmitting data of claim 70, further comprising substantially simultaneously transmitting the modulated information signal along a plurality of horizontally differentiated sectors.

72. The method of transmitting data of claim 70, further comprising transmitting a plurality of channel wavelengths over each of the plurality of vertically differentiated sectors.

73. The method of transmitting data of claim 70 wherein at least two of the plurality of vertically differentiated sectors have differing cross-sectional beam shapes.

74. The method of transmitting data of claim 70 wherein each of the plurality of vertically differentiated sectors includes information modulated at the same wavelength.

75. The method of transmitting data of claim 70 wherein the at least one carrier comprises a plurality of diverging coherent light beams transmitted along the plurality of vertically differentiated sectors.

76. A communication system, comprising:
a central node configured to split an input signal into a plurality of substantially similar output signals;
a plurality of transmitters disposed in the central node to transmit the plurality of output signals to a user node as light signals; and
a plurality of receivers disposed in the central node to receive a plurality of user signals from the user node.

77. The system of claim 76 wherein the plurality of user signals comprise light signals.

78. The system of claim 76 wherein the plurality of output signals comprise a substantially same information content as the input signal.

79. An apparatus, comprising:

an amplifier having an input port to receive an input signal and operable to divide the input signal into a plurality of output signals;
a plurality of transmitters to transmit the plurality of output signals; and
a plurality of receivers associated with respective plurality of transmitters to receive user signals.

80. The apparatus of claim 79 wherein the output signals and user signals comprise light signals.

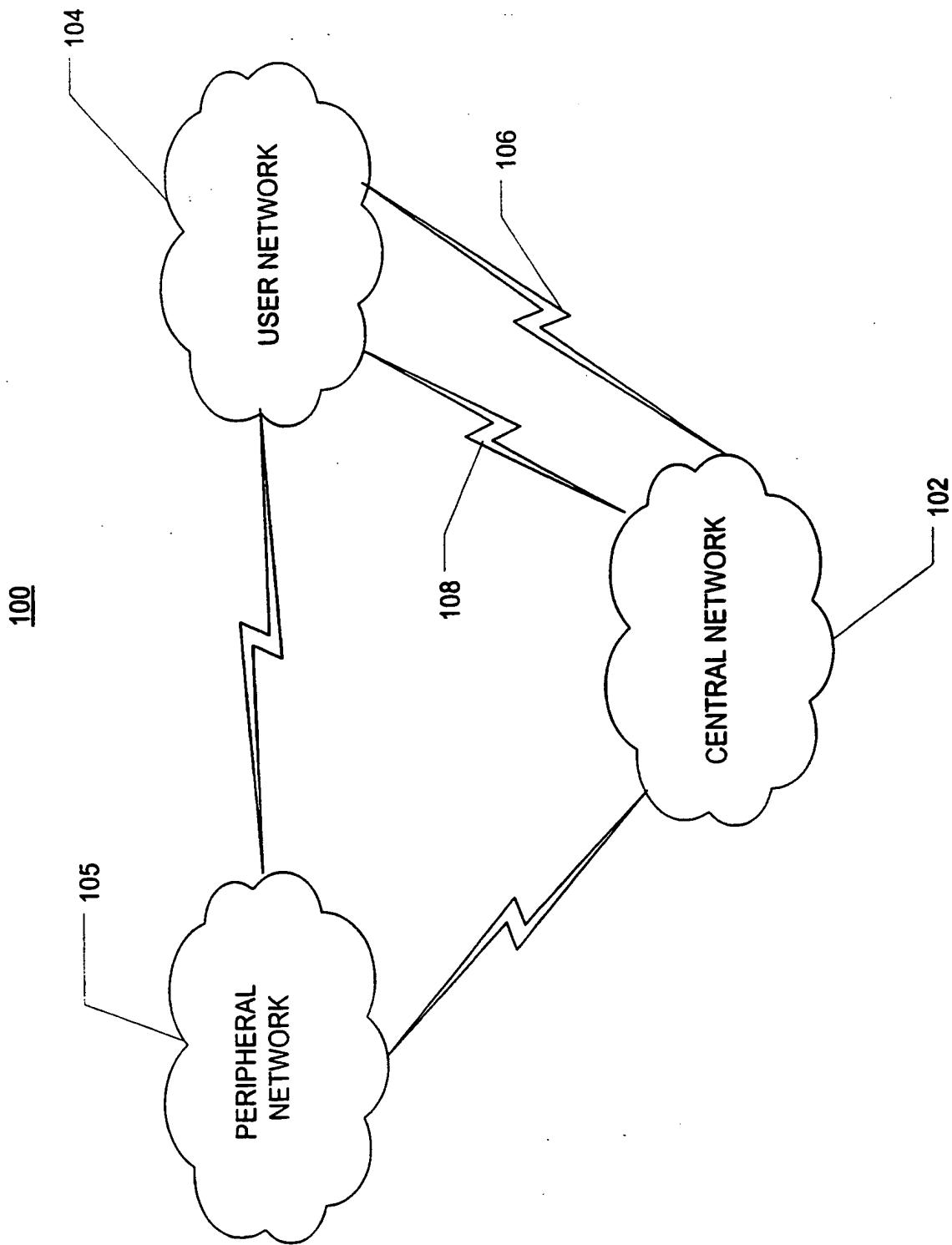
81. The apparatus of claim 79 wherein the plurality of output signals comprise a substantially same information content as the input signal.

82. A method of transmitting and receiving, the method comprising:
dividing an input signal into a plurality of output signals;
transmitting the plurality of output signals to a plurality of corresponding receivers of a user node; and
receiving a plurality of user signals transmitted from the user node light signals.

83. The method of claim 82 wherein transmitting the plurality of output signals comprises transmitting light signals.

84. The method of claim 82, further comprising providing each of the plurality of output signals with a substantially same information content as the input signal.

FIG. 1A



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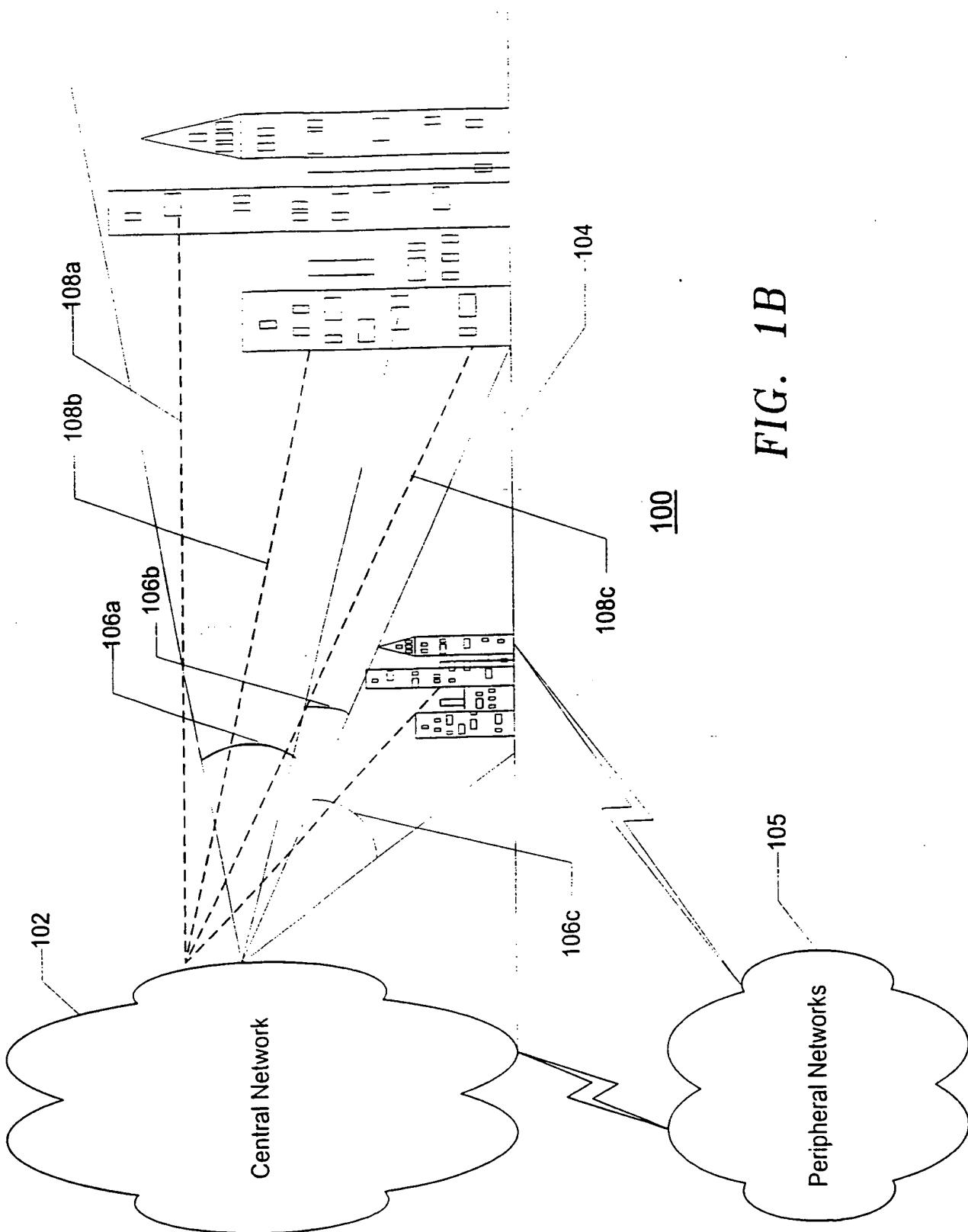


FIG. 1B

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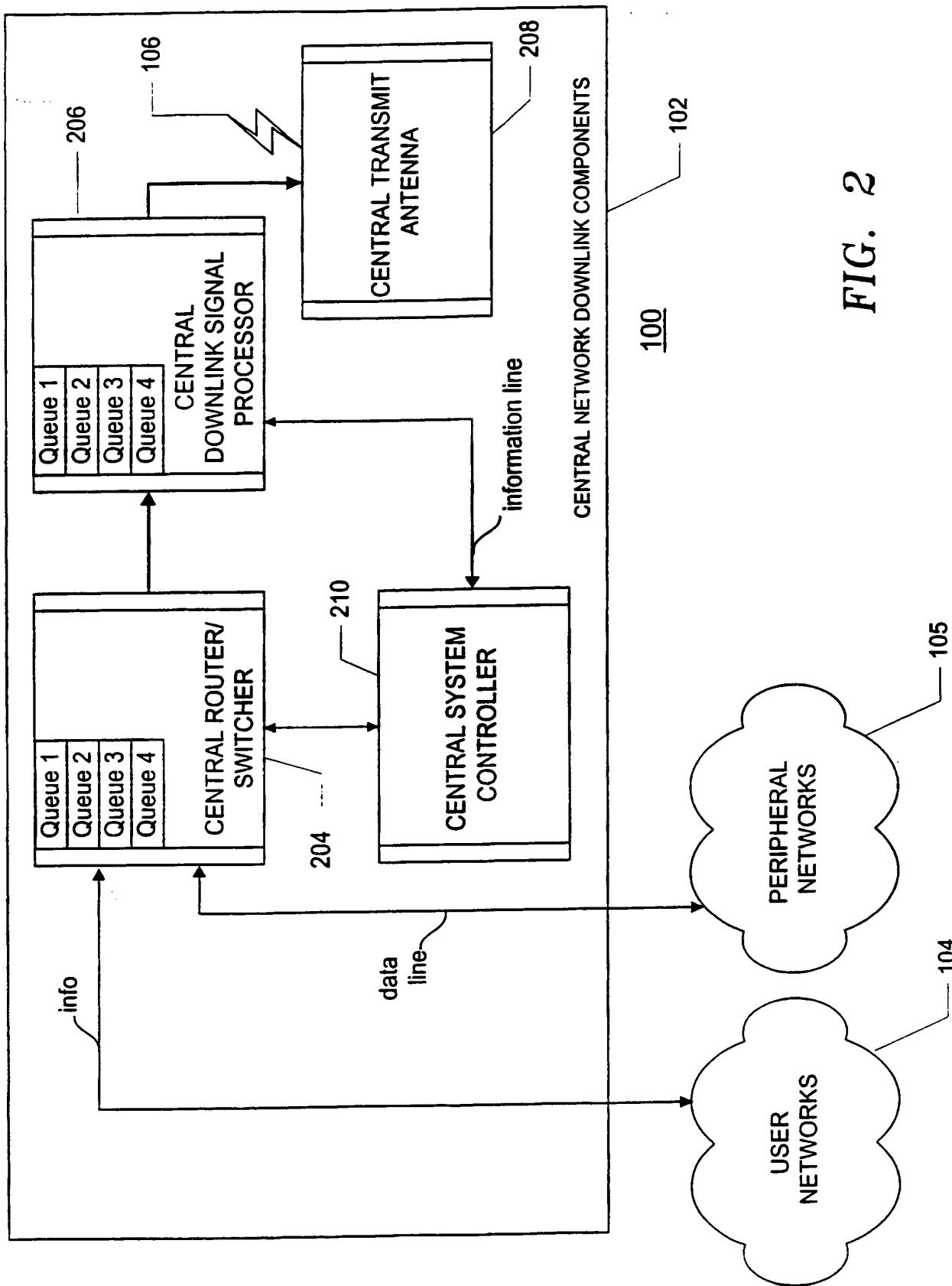


FIG. 2

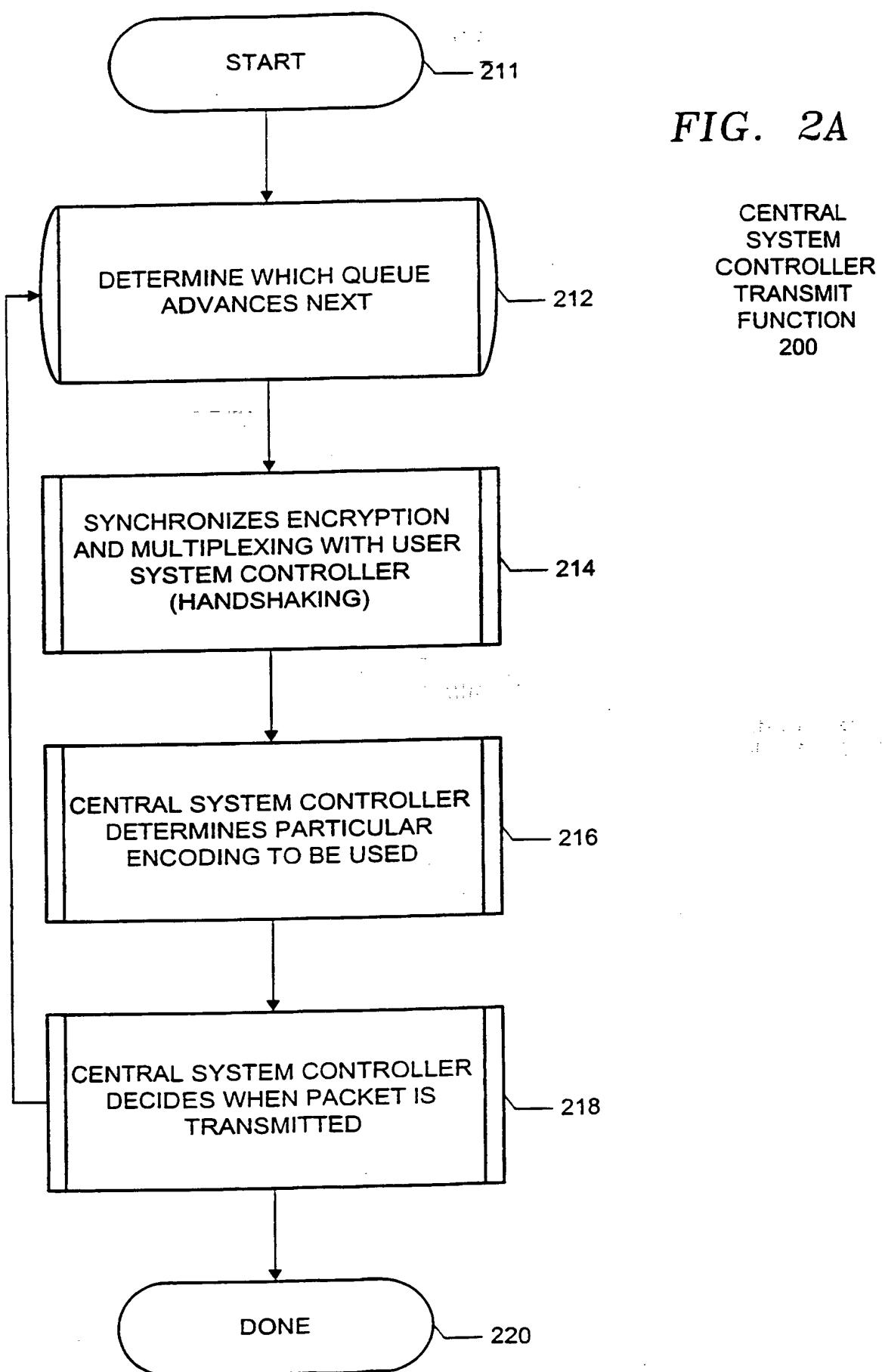
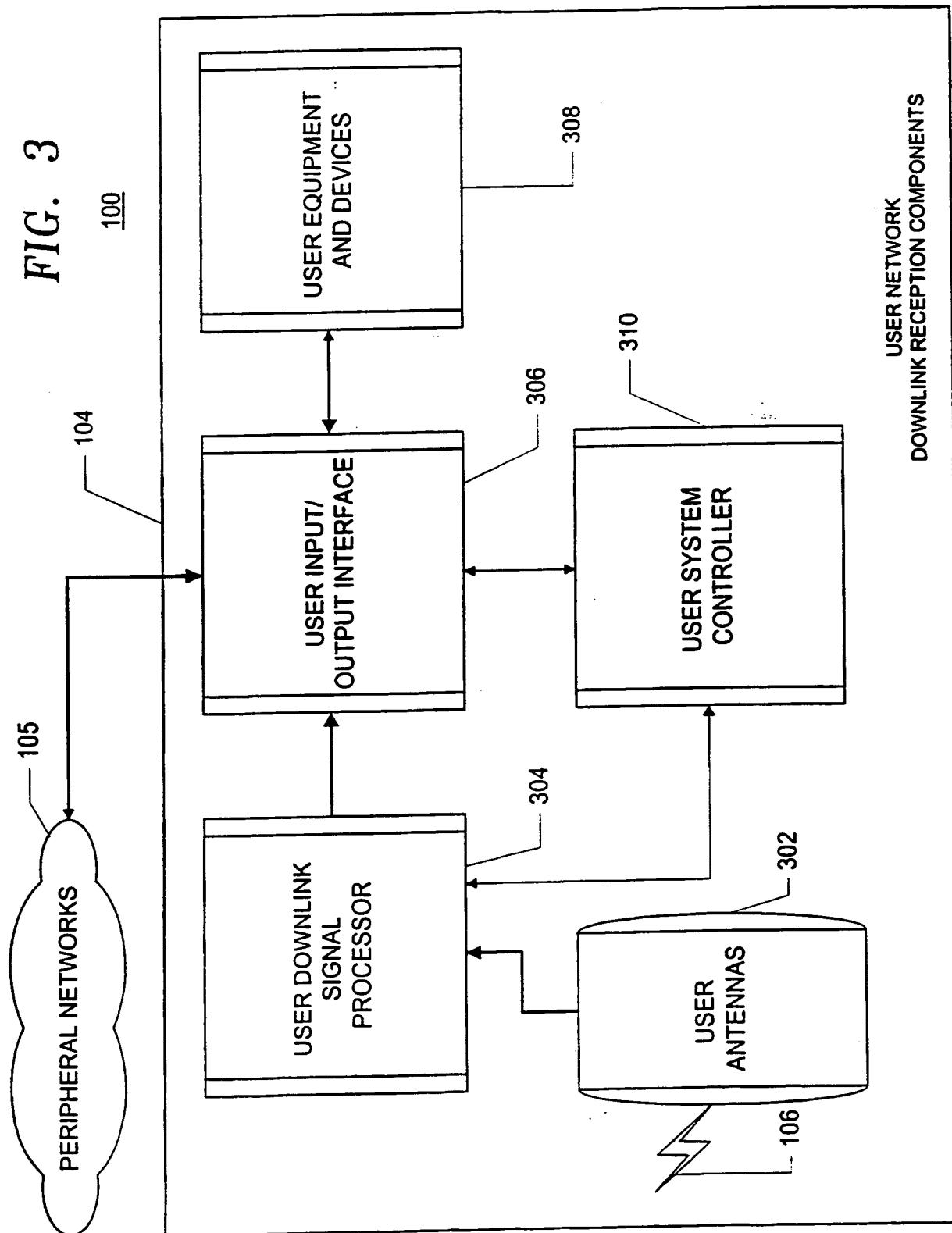


FIG. 3



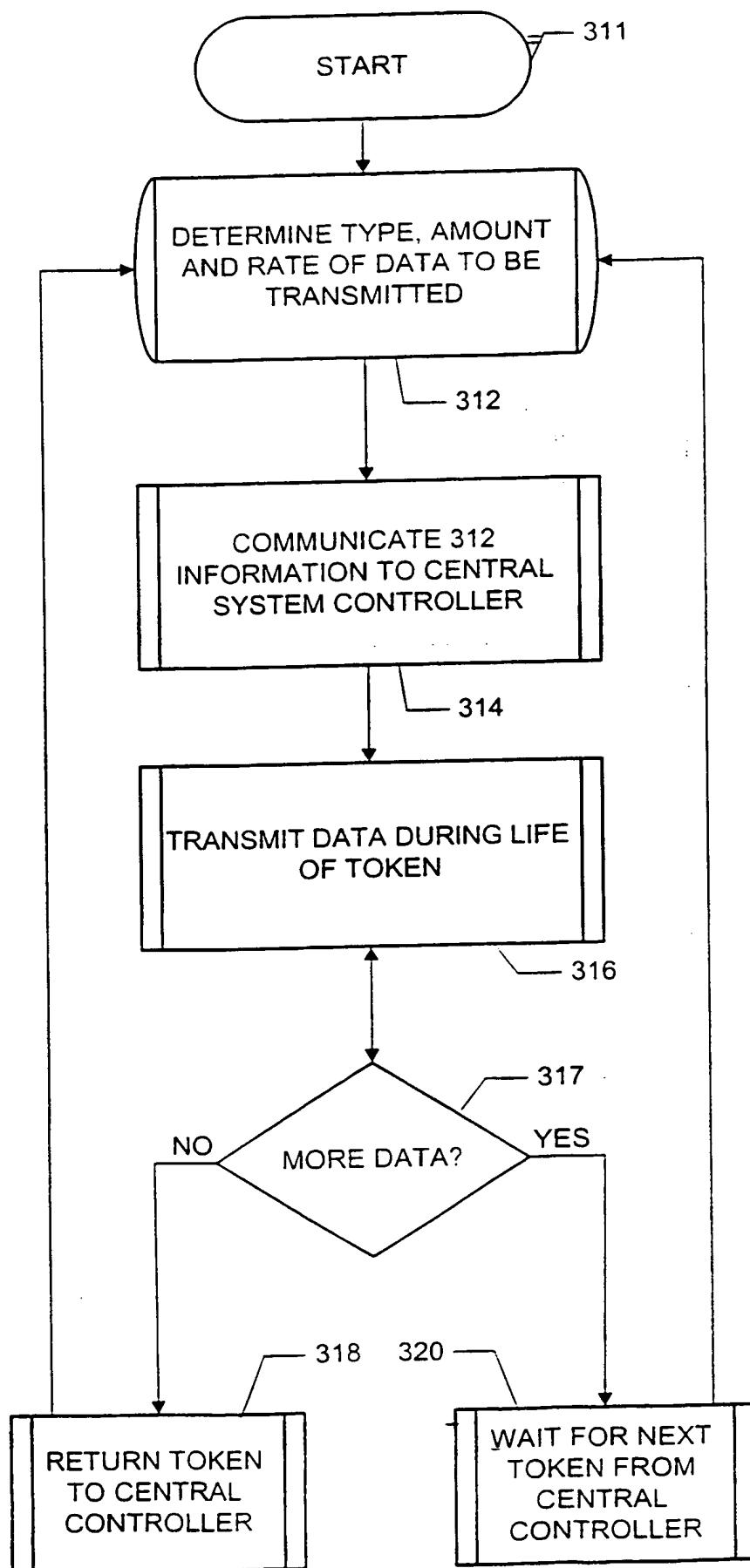
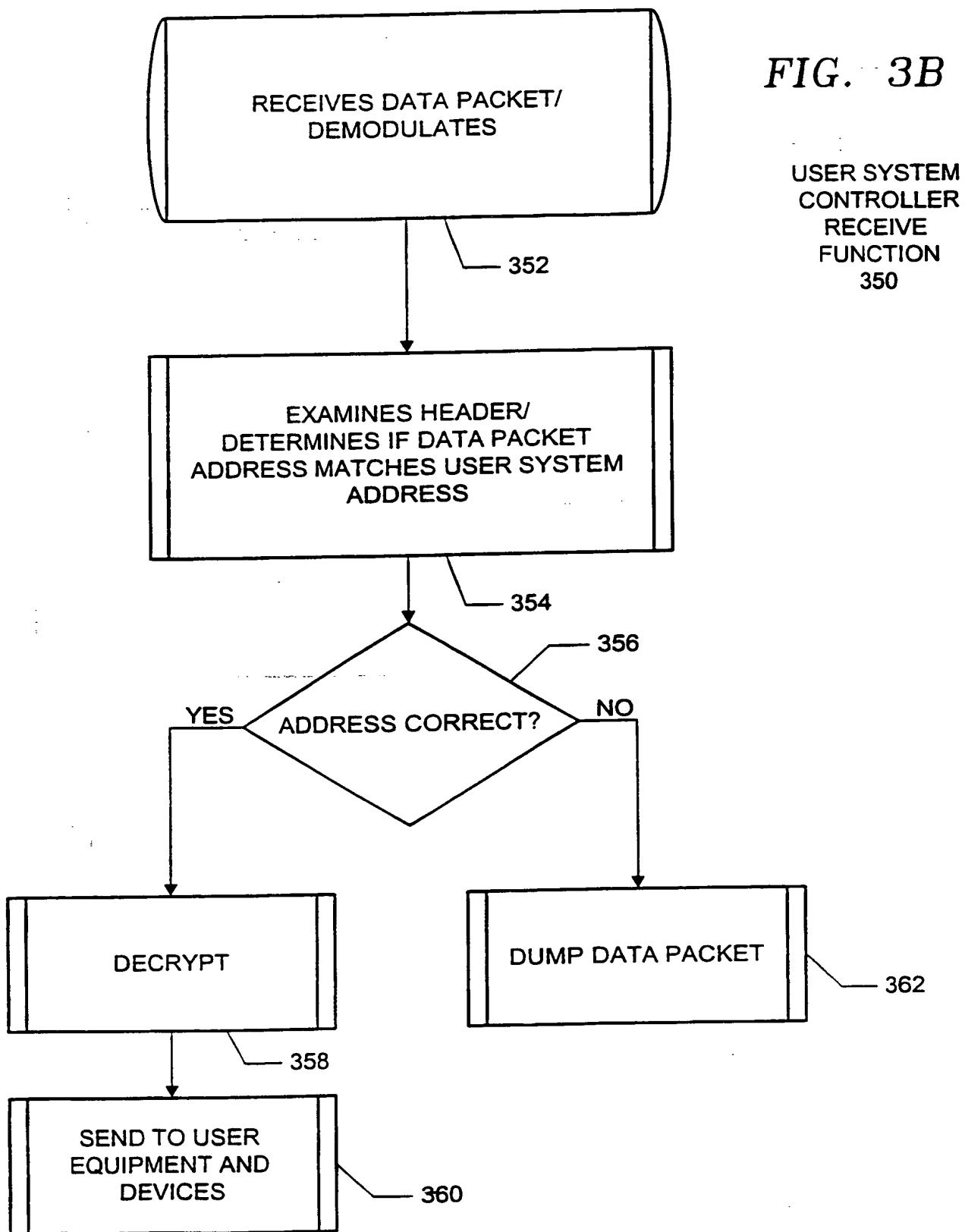


FIG. 3A
USER SYSTEM
CONTROLLER
TRANSMIT
FUNCTION
WITH A TOKEN
RING TIME
DIVISION
MULTIPLEXING
(TDM) SYSTEM
300



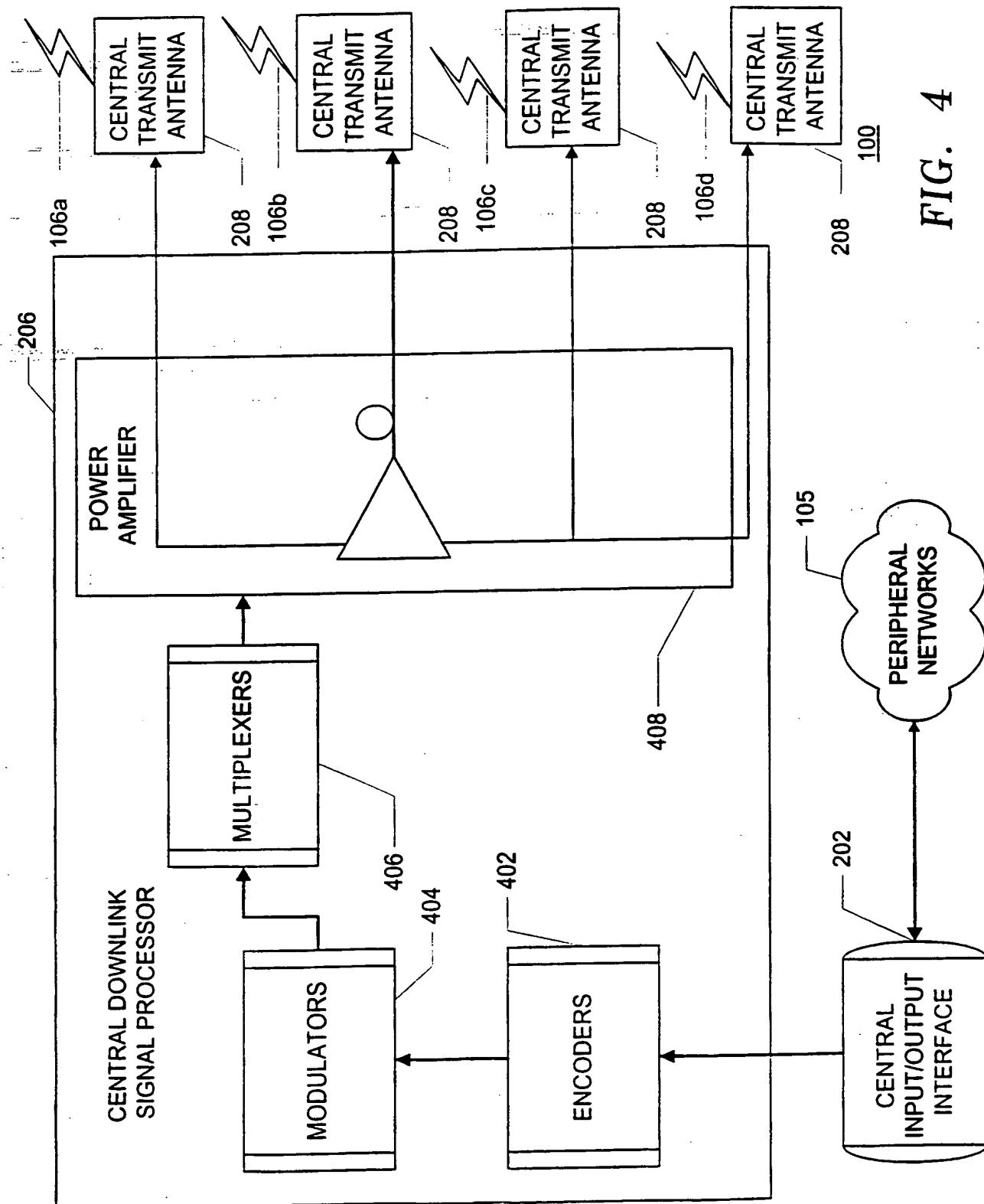


FIG. 4

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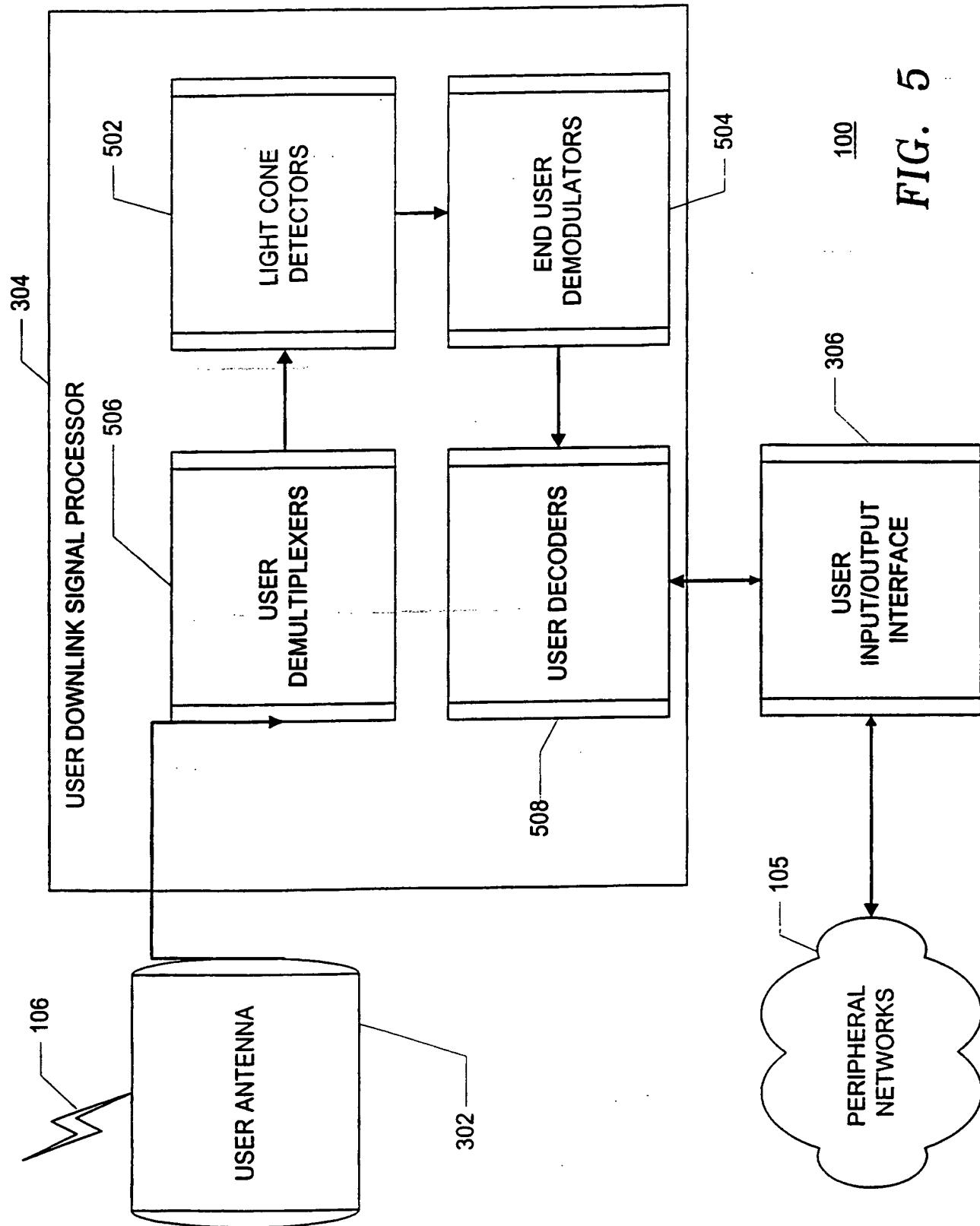
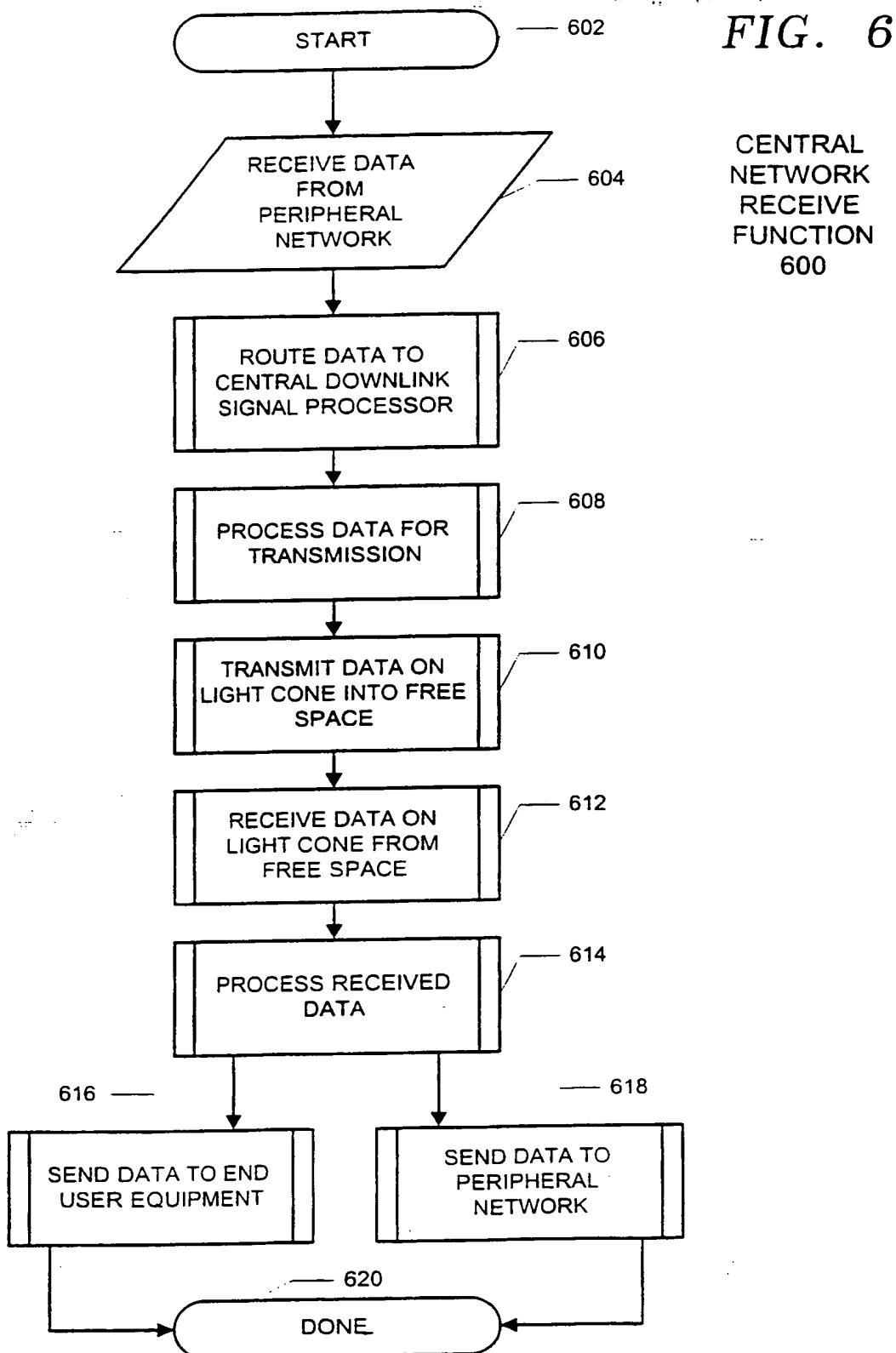
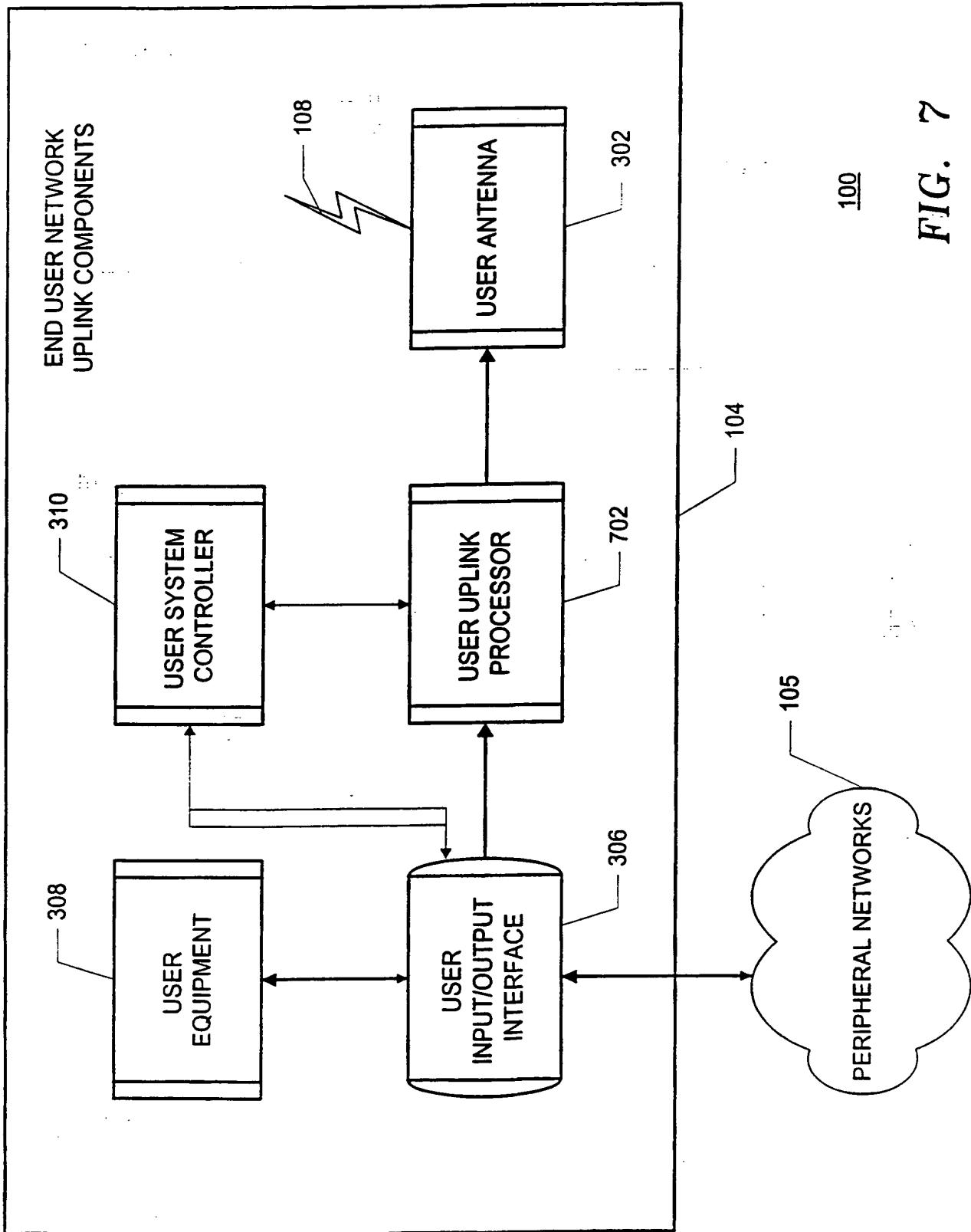


FIG. 5

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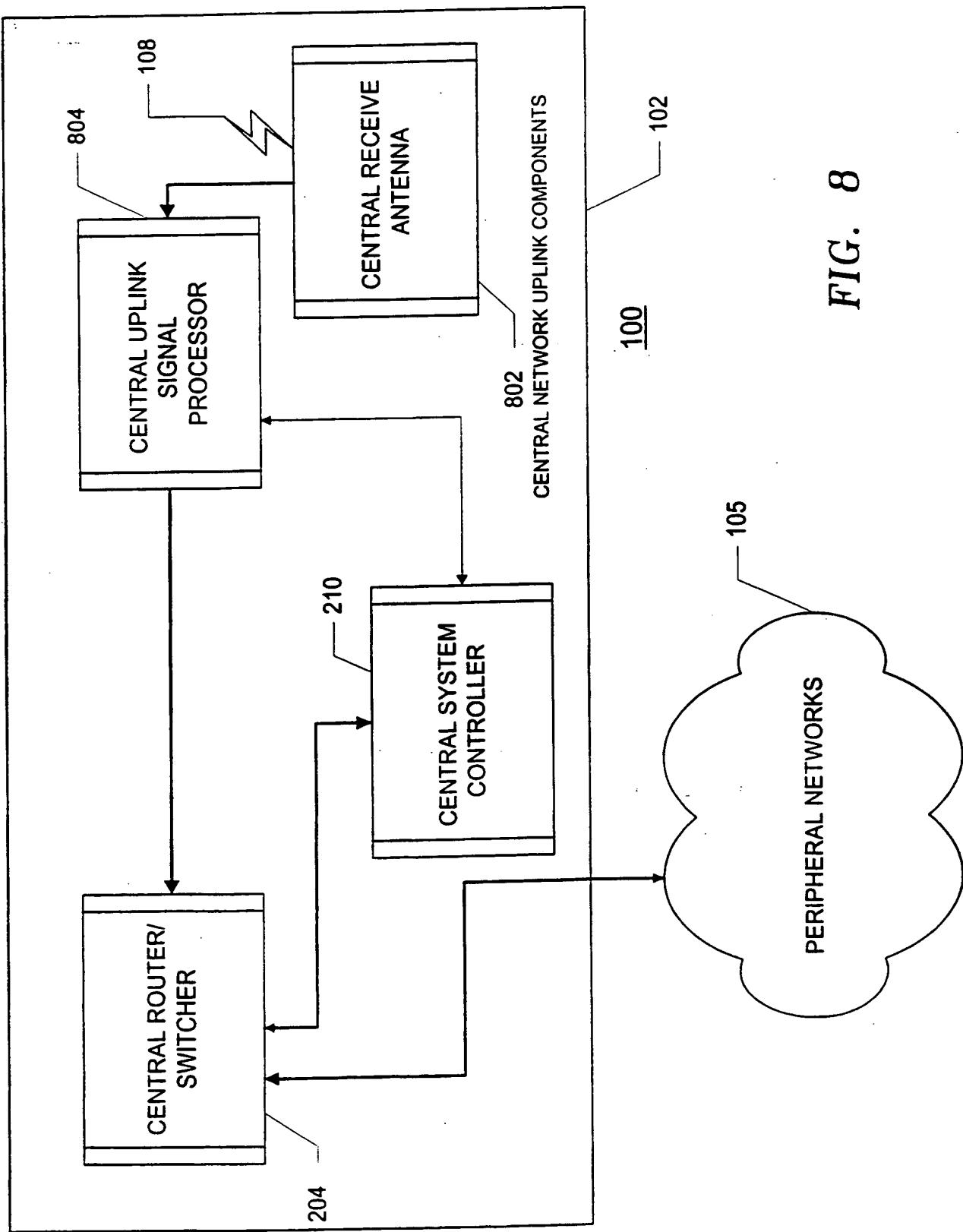


FIG. 8

FIG. 9

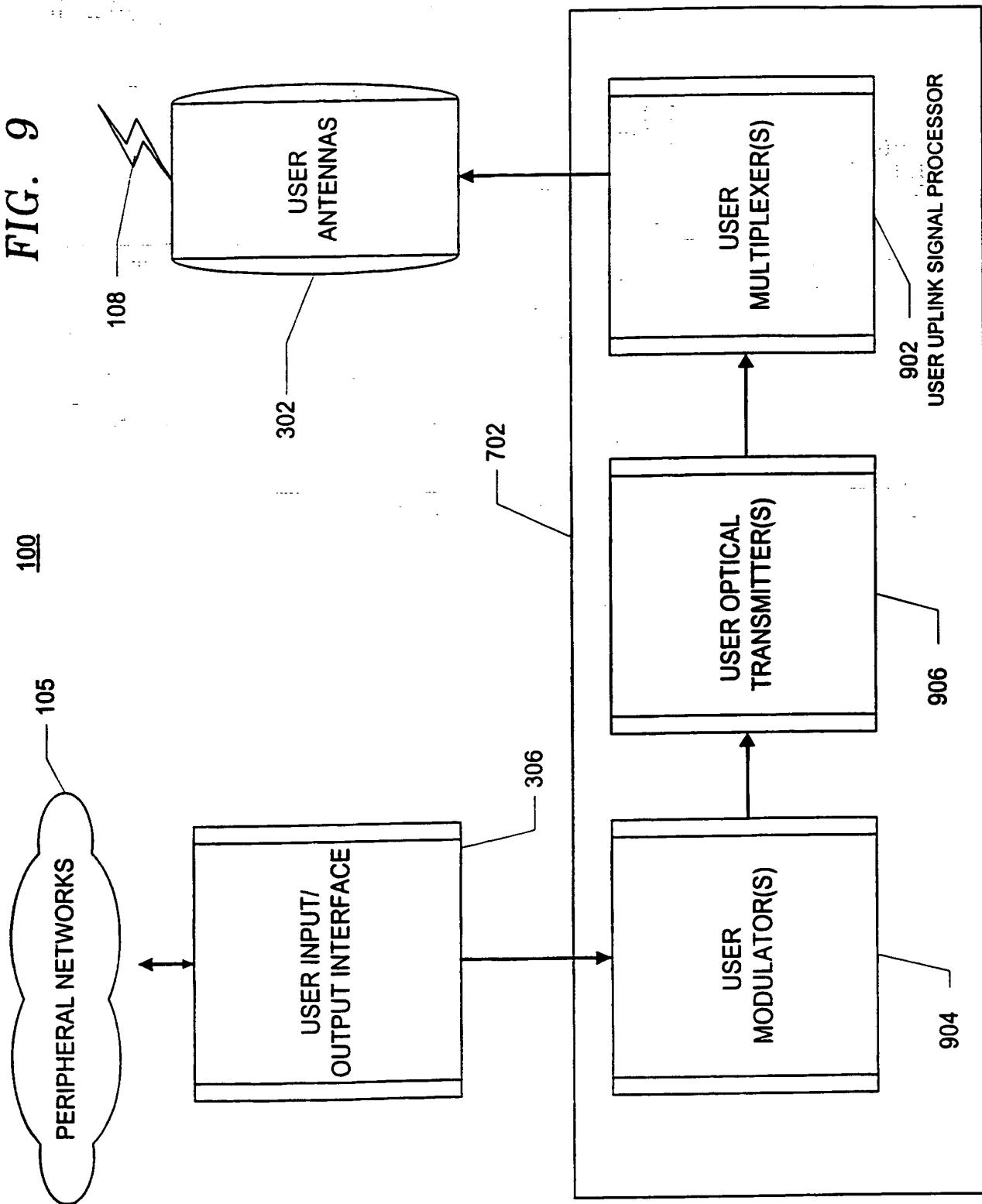
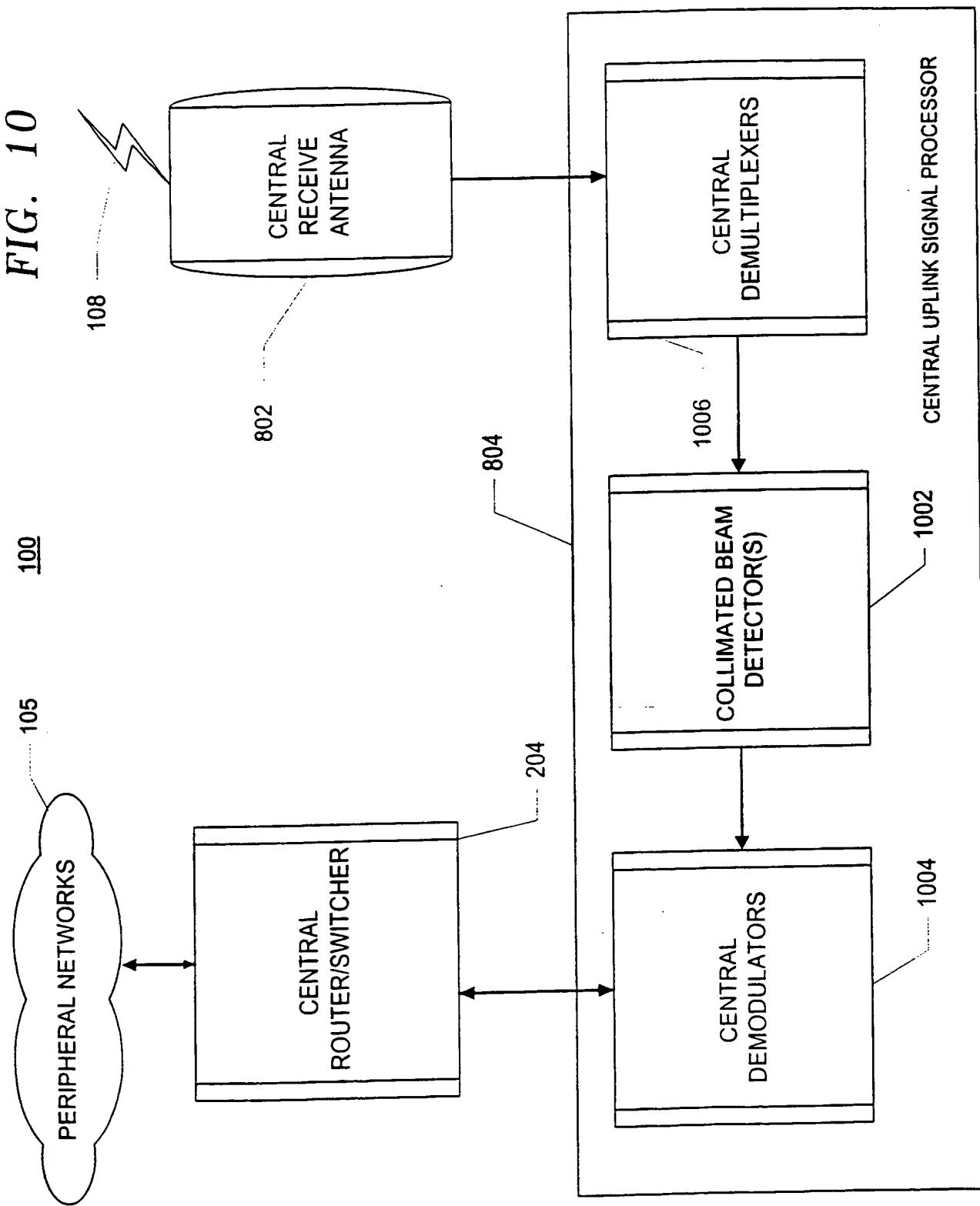
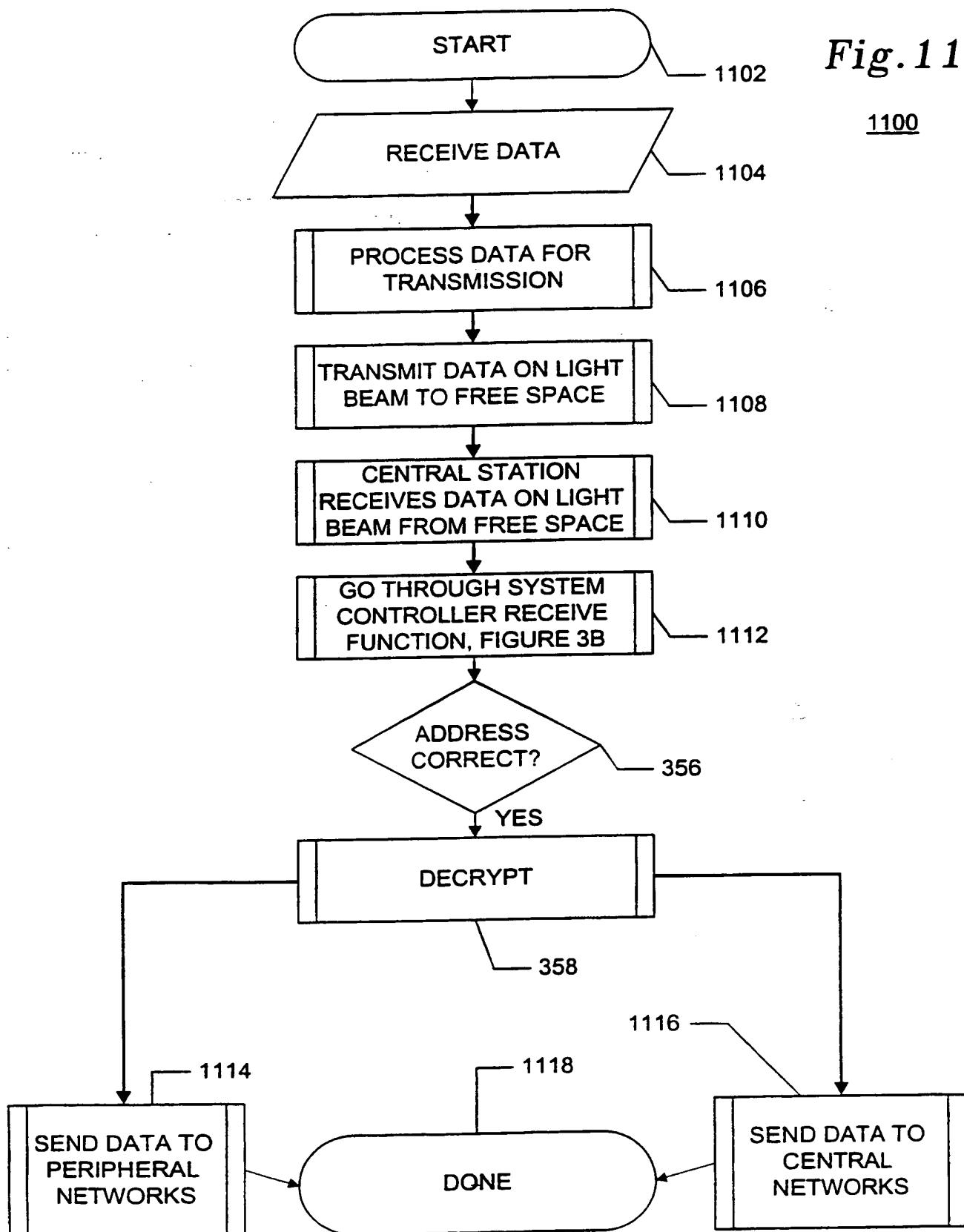


FIG. 10



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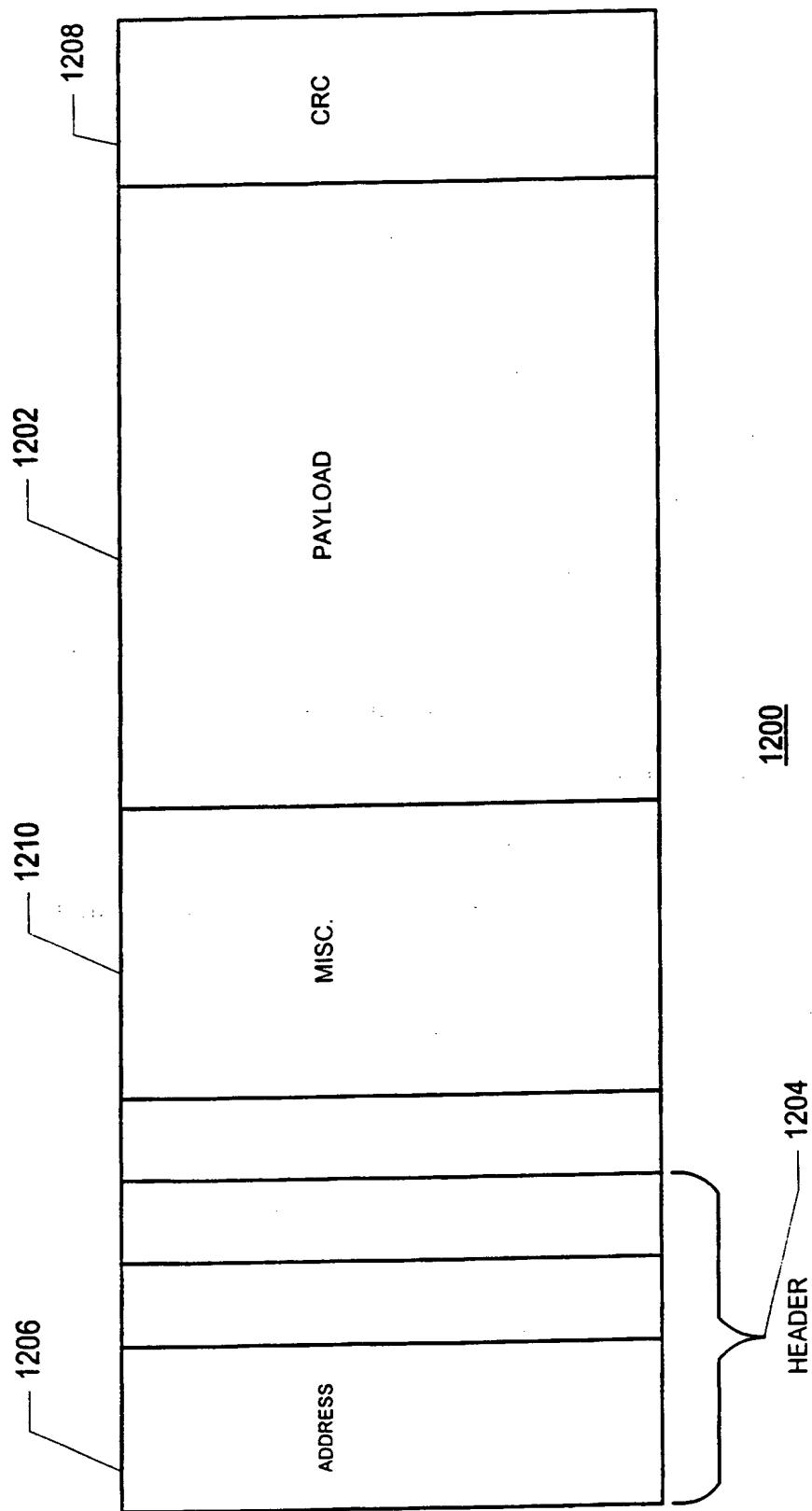


FIG. 12

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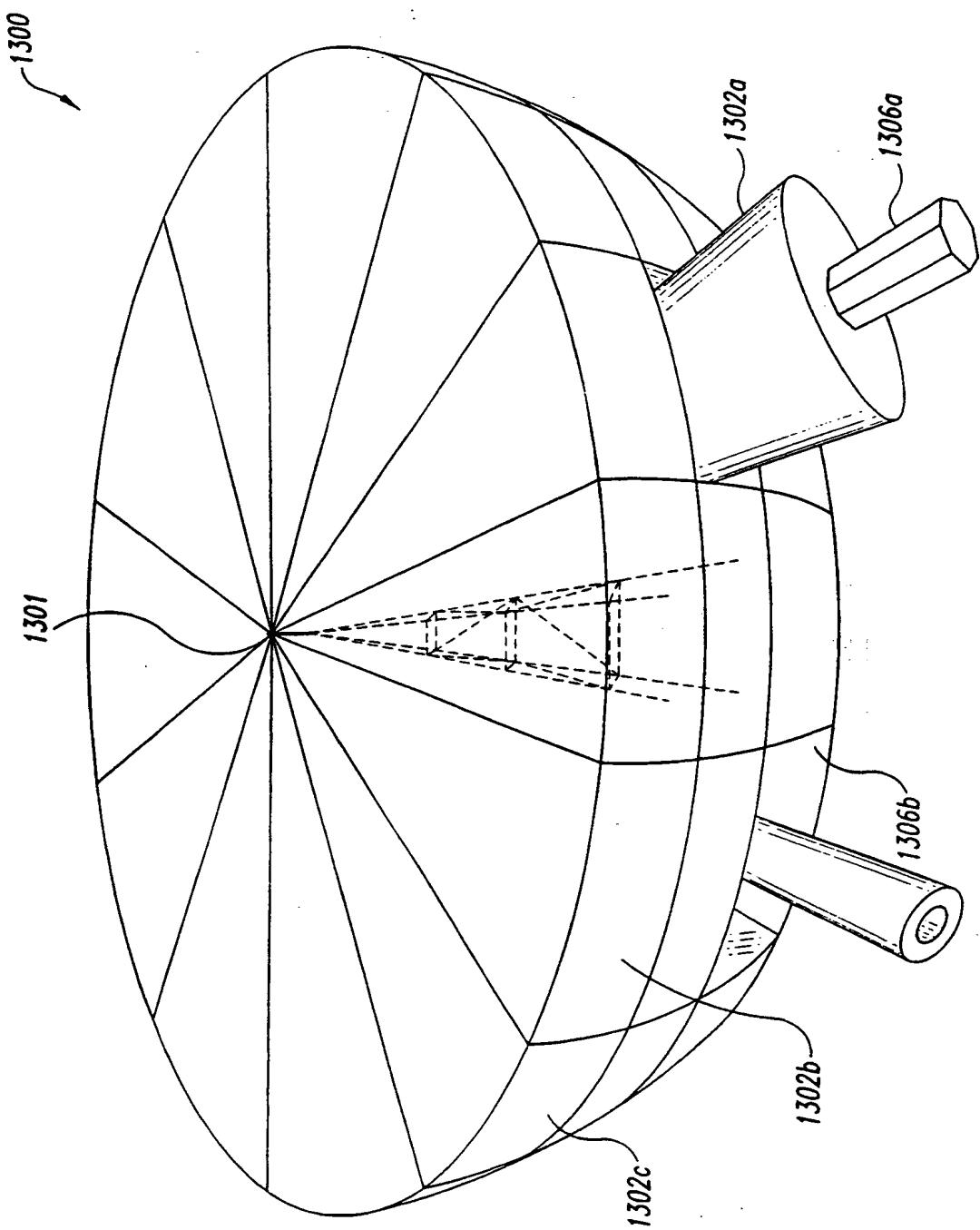


Fig. 13

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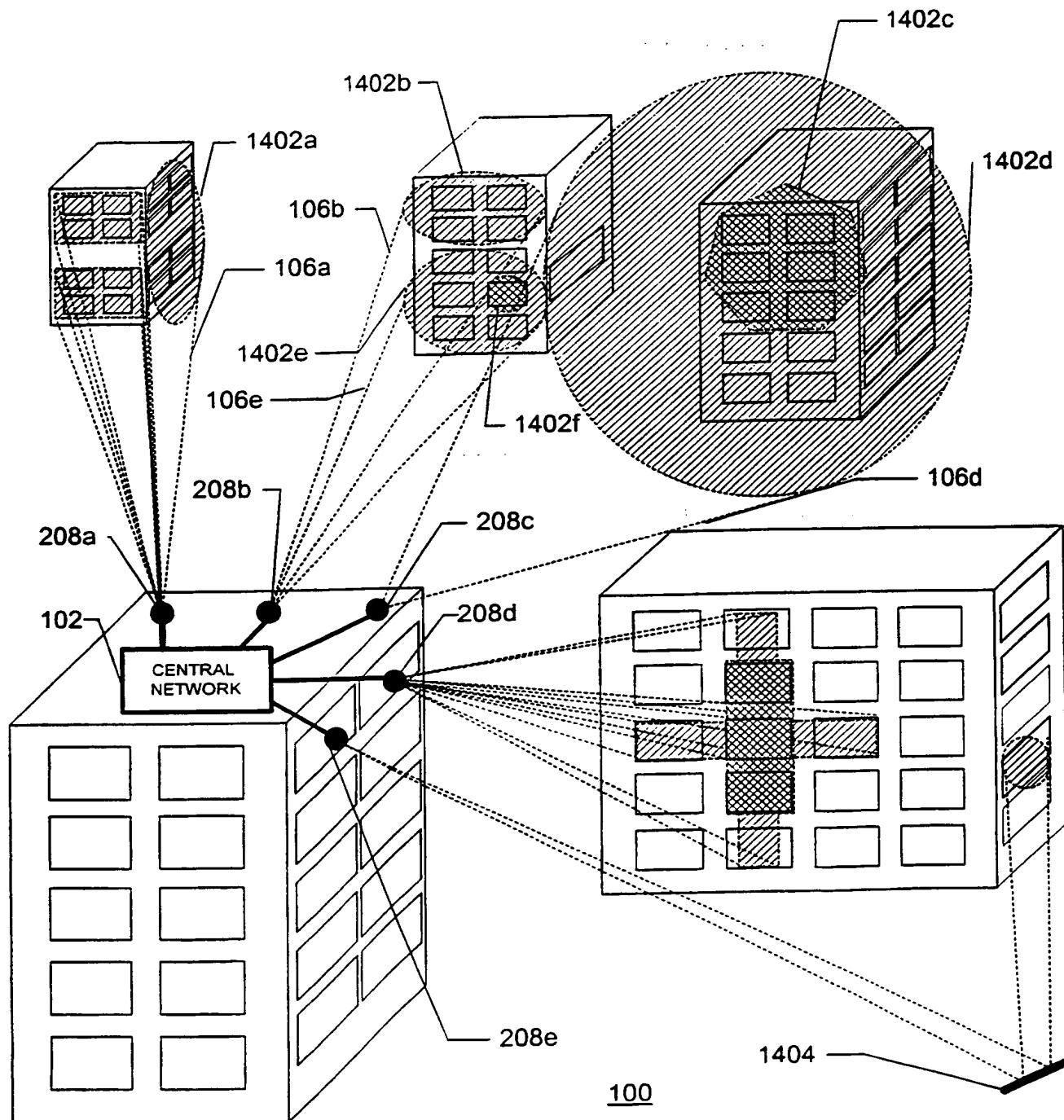


FIG. 14

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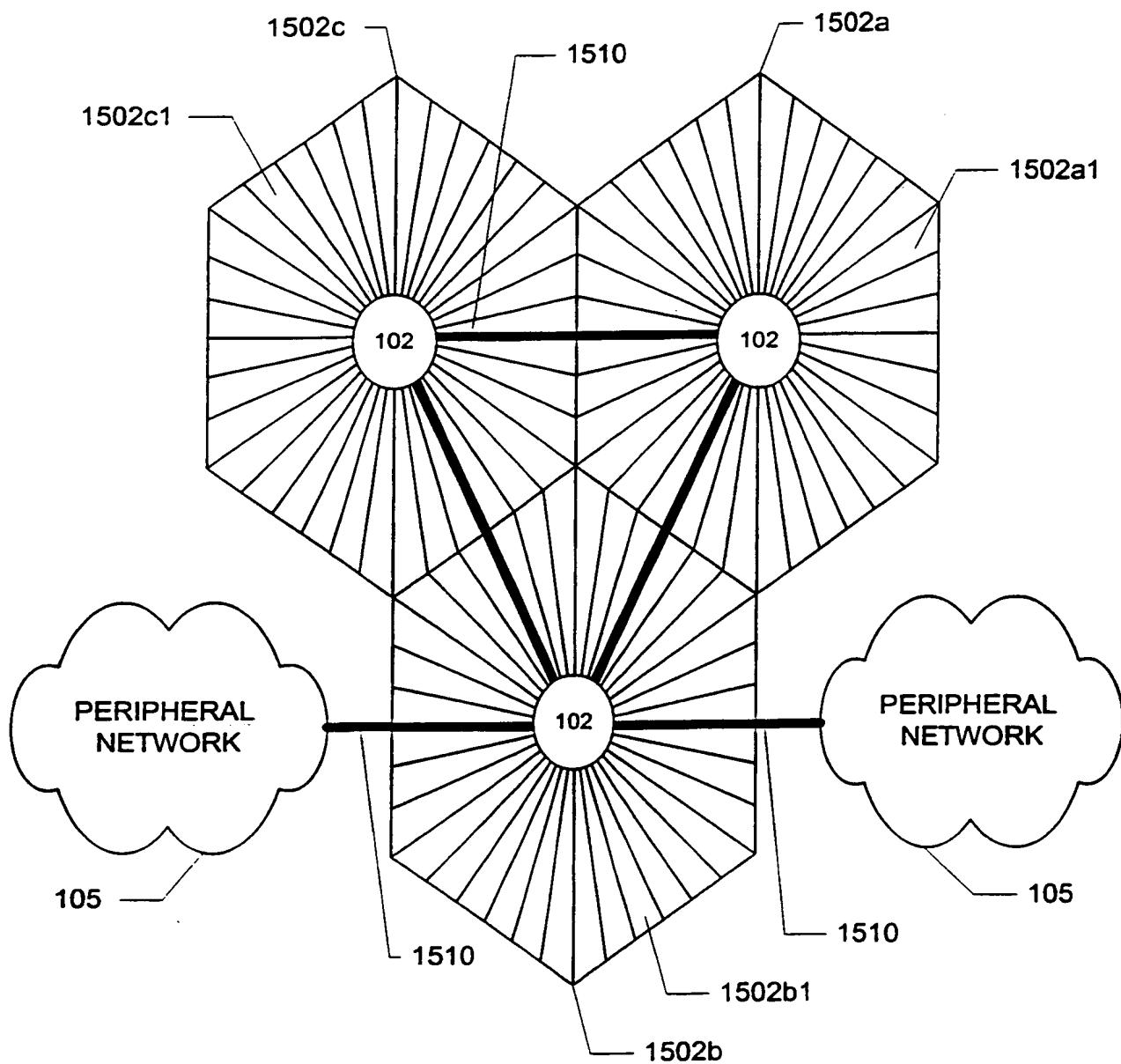
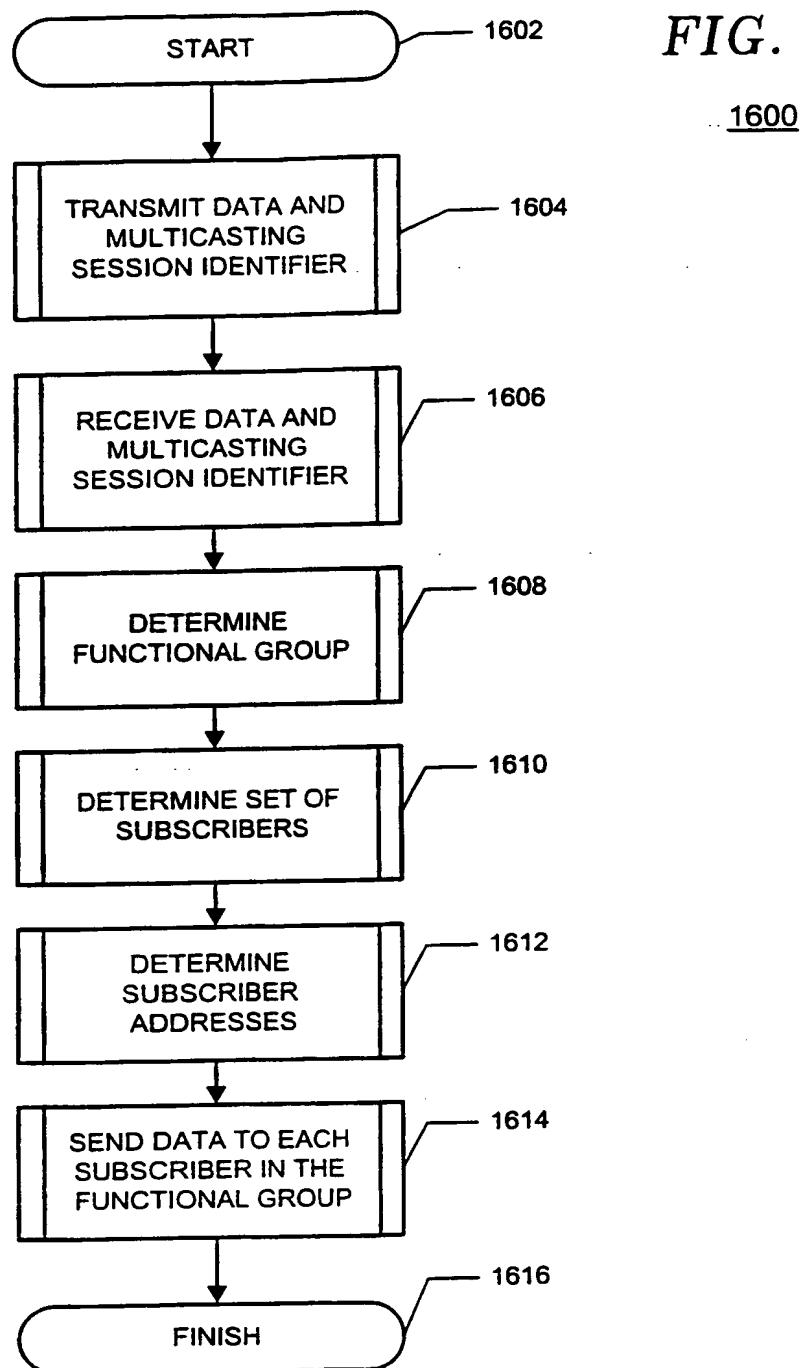
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FIG. 15

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FIG. 16



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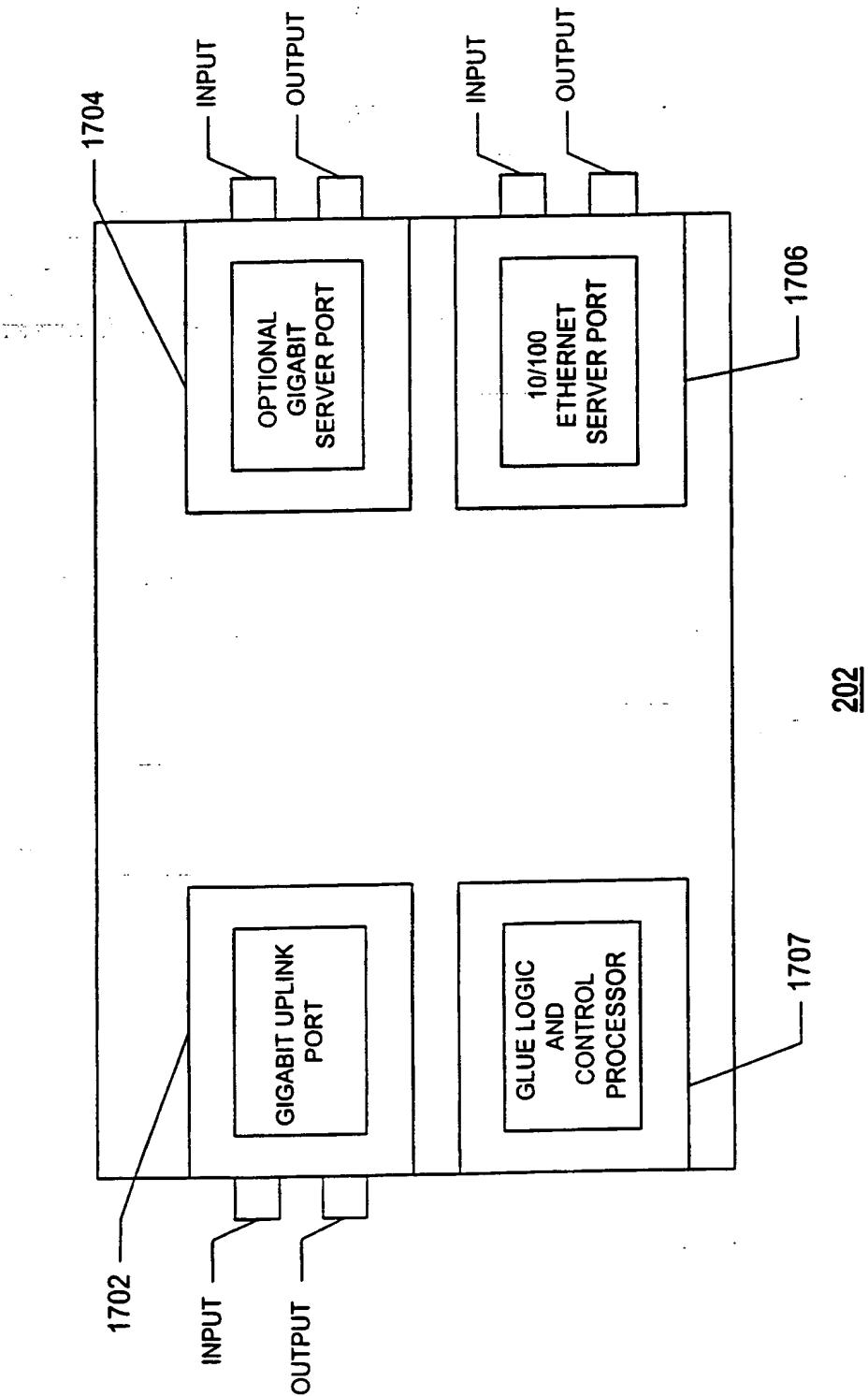


FIG. 17

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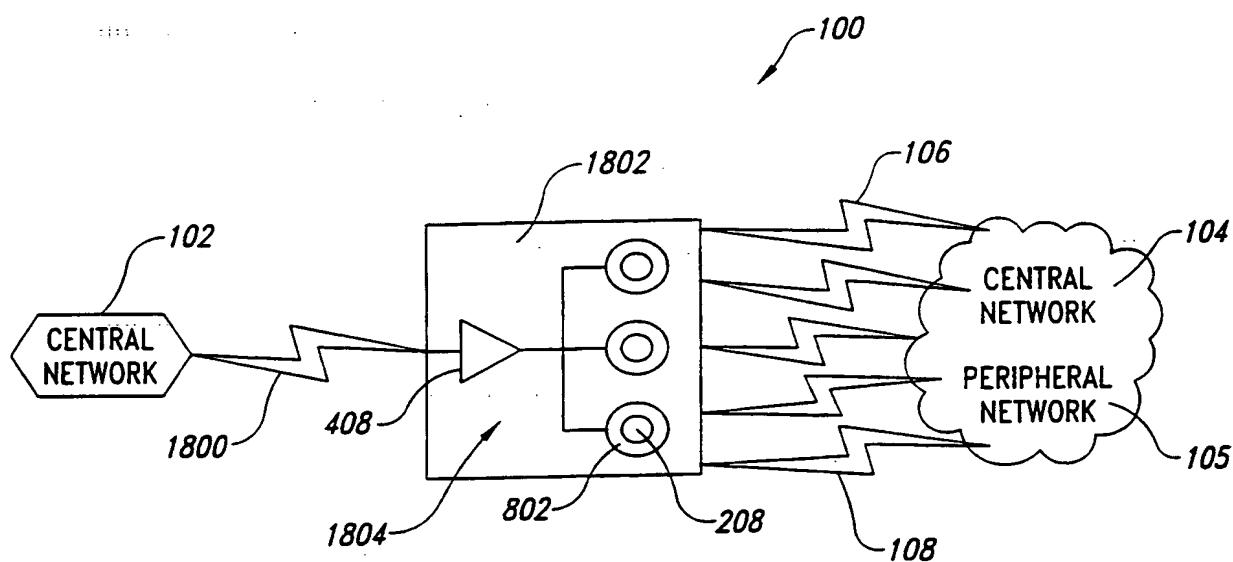


Fig. 18

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 99/15973A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04B10/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the International search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|------------|--|---|
| X | WO 97 37445 A (DOMINION COMMUNICATIONS L L C) 9 October 1997 (1997-10-09) abstract; figures 1-10 | 1,26, 62-66,68 2-18, 21-25, 27-33, 35-43, 45, 48-50, 55,67, 69,72, 75-84 34,44, 46,52, 59-61 |
| Y | | |
| A | page 2, line 6 -page 3, line 9 page 4, line 1 -page 5, line 12 page 5, line 29 - line 37 page 7, line 31 -page 8, line 16 page 9, line 1 -page 10, line 19 page 18, line 20 - line 21 | -/- |

 Further documents are listed in the continuation of box C. Patent family members are listed in annex.

* Special categories of cited documents :

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the International filing date
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"T" later document published after the International filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"Z" document member of the same patent family

Date of the actual completion of the International search

Date of mailing of the International search report

7 March 2000

17.03.2000

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Authorized officer

Goudelis, M

INTERNATIONAL SEARCH REPORT

Int'l. Application No
PCT/US 99/15973

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

| Category | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|----------|--|---|
| | page 20, line 37 -page 21, line 11 page 21, line 38 - line 40 | |
| X | US 5 748 813 A (CASSIDY STEPHEN ANTHONY ET AL) 5 May 1998 (1998-05-05) | 70,71,74 |
| Y | column 1, line 47 - line 67; figures 1,6 | 30,31, 67,72, 75-84 |
| A | column 1, line 47 - line 64 | 19,20, 22,35 |
| Y | EP 0 653 852 A (CANON KK) 17 May 1995 (1995-05-17) | 2,10-18, 21-25, 27-29, 32,33, 35-43, 45, 48-50,55 |
| | column 5, line 40 -column 6, line 46 column 7, line 45 -column 8, line 13; figures 3-5 | |
| Y | MERCER L B: "ADAPTIVE COHERENT OPTICAL RECEIVER ARRAY" ELECTRONICS LETTERS, vol. 26, no. 18, 30 August 1990 (1990-08-30), pages 1518-1520, XP00010861 ISSN: 0013-5194 page 1518, right-hand column, last paragraph -page 1519, left-hand column, paragraph 2; figures 1,2 | 3 |
| Y | US 5 737 690 A (GUTMAN JOSE) 7 April 1998 (1998-04-07) | 4-9 |
| A | abstract; figures 1,3 | 1,3,26, 37,39,40 |
| | column 4, line 19 - line 60 column 12, line 34 -column 13, line 26 | |
| Y | PATENT ABSTRACTS OF JAPAN vol. 017, no. 563 (P-1628), 12 October 1993 (1993-10-12) & JP 05 164532 A (MITSUBISHI ELECTRIC CORP), 29 June 1993 (1993-06-29) abstract | 69 |
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| | claims 1-4; figures 1-6 | |

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 99/15973

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. Claims Nos.: because they relate to subject matter not required to be searched by this Authority, namely:

2. Claims Nos.: because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. Claims Nos.: because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

The additional search fees were accompanied by the applicant's protest.

No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International Application No. PCT/US 99/15973

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. Claims: 1-3,26-31,37-40

Communication system and method for transmitting and receiving data between peripheral points and user points via a central point using free space modulated light beams.

2. Claims: 4-9

Central point to user communication method using modulation of data and user address on a light beam.

3. Claims: 10-25,32-36,41-61

Free space light transmission system, apparatus and method using information modulation on a diverging coherent light beam.

4. Claims: 62-75

Data transmission system and method transmitting information along several sectors.

5. Claims: 76-84

Communication system with a central node splitting an input signal into plural substantially similar output signals and transmitting them optically to a user node as well as receiving a plurality of optical signals.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 99/15973

| Patent document cited in search report | Publication date | Patent family member(s) | | | Publication date |
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